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ENVIRO

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Problem

Spills

SODIUM CHLORATE

March 1985

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ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS MANUALS

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals provide detailed information on chemical substances. This information is intended to assist the reader in designing countermeasures for spills and to assess their impact on the environment. The report has been reviewed by the Technical Services Branch, Environmental Protection Service, and approved for publication. Approval does not signify that the contents reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

EnviroTIPS manuals are available from:

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SODIUM CHLORATE

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS

Technical Services Branch
Environmental Protection Programs Directorate
Environmental Protection Service
Ottawa, Ontario

March 1985

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FOREWORD

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals were initiated in 1981 to provide comprehensive information on chemicals that are spilled frequently in Canada. The manuals are intended to be used by spill specialists for designing countermeasures for spills and to assess their effects on the environment. The major focus of EnviroTIPS manuals is environmental. The manuals are not intended to be used by first-response personnel because of the length and technical content; a number of manuals intended for first-response use are available. The information presented in this manual was largely obtained from literature review. Efforts were made, both in compilation and in review, to ensure that the information is as correct as possible. Publication of these data does not signify that they are recommended by the Government of Canada, nor by any other group.

ACKNOWLEDGEMENTS

The final version of this manual was prepared by the staff of the Environmental Protection Service who wrote extensive revisions to the text, drafted illustrations and incorporated all comments and additions.

The level of detail present was made possible by the many individuals, organizations and associations who provided technical data and comments throughout the compilation and subsequent review. The Canadian Chemical Producers' Association is especially acknowledged for its review of and input to this manual. The draft of this manual was prepared under contract to Environment Canada by M.M. Dillon Consulting Engineers and Planners, Concord Scientific Corporation, and Waterloo Engineering Limited.

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1 SUMMARY

SODIUM CHLORATE ($NaClO_3$)

White to yellow crystals, or yellow to orange liquid; odourless

SYNONYMS

Chlorate of soda, sodium salt of chloric acid

IDENTIFICATION NUMBERS

UN No. 1495 (solid), 2428 (solution); CAS No. 7775-09-9; OHM-TADS No. 7216890; STCC No. 4918723

GRADES & PURITIES

Technical, solid: 99-99.9 percent; solution: 25-46 percent

IMMEDIATE CONCERNS

Fire: A powerful oxidizing agent

Human Health: Toxic by ingestion; prolonged contact may cause irritation

Environmental: Harmful to aquatic life in high concentrations

PHYSICAL PROPERTY DATA

State (15°C, 1 atm): solid
Boiling Point: decomposes at 265°C
Melting Point: 248 to 261°C
Flammability: not combustible, but may cause combustible materials to ignite

Specific Gravity: 2.49 (15°C)
Solubility (in water): 95.7 g/100 mL (20°C)
Behaviour (in water): sinks and mixes; no reaction
Odour Threshold: odourless

ENVIRONMENTAL CONCERNS

Sodium chlorate is toxic to aquatic life in high concentrations - from 1000 to 10 000 mg/L

HUMAN HEALTH

No TLV® or IDLH established

Exposure Effects

Inhalation: Irritation of mucous membranes; respiratory difficulties

Contact: Irritation to skin and eyes on prolonged contact

Ingestion: Nausea, vomiting, diarrhea, abdominal pain, cyanosis, kidney and liver injury; possible convulsions, coma and death with a heavy dose

IMMEDIATE ACTION

Spill Control

Restrict access to spill site. Issue warning: "OXIDIZER". Notify manufacturer. Keep unnecessary personnel away from site. Stop the flow and contain spill, if safe to do so. Avoid contact with material. Keep spilled material away from combustibles or organics. Keep contaminated water from entering sewers or watercourses.

Fire Control

Not combustible. Use water to extinguish fires involving sodium chlorate. Other extinguishing agents are ineffective. Cool fire-exposed containers with water spray. Containers may explode in heat of fire.

COUNTERMEASURES

Emergency Control Procedures in/on

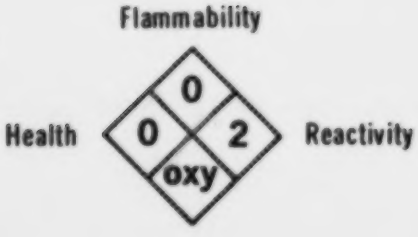
Soil: Construct barriers to contain spill. For solid, collect as much as possible into clean, dry container (preferably metal) and cover tightly. Wash down area to remove residue. For solutions, recover as much as possible with pumps or vacuum equipment. Wash area to remove and dilute the residue

Water: Contain by damming, water diversion or natural barriers

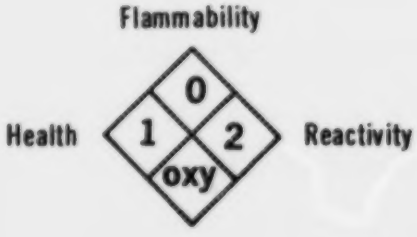
NAS HAZARD RATING

NFPA
HAZARD
CLASSIFICATION

NON-FIRE



FIRE



2 PHYSICAL AND CHEMICAL DATA

Physical State Properties

Appearance	Solutions: yellow to orange liquid (CCPA 1983) Commercial solid: white to slightly yellow lumps (CCPA 1983) Pure solid: white crystalline solid with cubic or trigonal crystal form (Erco PIM; Hooker PIM)
Usual shipping state(s)	Solid or liquid (aqueous solution)
Physical state at 15°C, 1 atm	Solid
Melting point	248-261°C (CRC 1983)
Boiling point	Decomposes before boiling (Hooker PIM)

Densities

Density	2.487 g/cm^3 (25°C) (Ullmann 1975)
Specific gravity	2.49 (15°C) (Erco PIM)

Fire Properties

Flammability	Nonflammable, oxidizing agent (NFPA 1978)
Decomposition temperature	265°C (Kirk-Othmer 1979)
Behaviour in a fire	Extreme fire hazard if mixed with material that will burn (such as clothing, wood, paper, etc.). These mixtures may be ignited by friction or heat (Erco PIM; Kerr-McGee MSIS 1978). Sealed drums exposed to heat can explode (CCPA 1983)

Other Properties

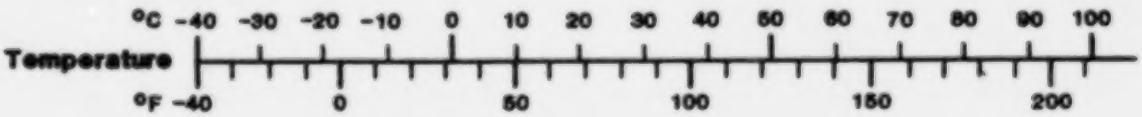
Molecular weight of pure substance	106.44 (CRC 1980)
Constituent components of typical commercial grade	Solid: 99 to 99.5 percent $NaClO_3$, remainder mostly NaCl and H_2O Solutions: 25 to 46 percent $NaClO_3$, remainder mostly H_2O and NaCl
Refractive index	1.515 (20°C) (Kirk-Othmer 1979)
Hygroscopicity	Slightly hygroscopic (Kirk-Othmer 1979)
Latent heat of fusion	22.1 kJ/mole (at melting point) (CRC 1980)

Heat of formation	-358.7 kJ/mole (25°C) (Lange's Handbook 1979)
Enthalpy	136 J/(mole-K) (Ullmann 1975)
Heat of solution	22.1 kJ/mole (infinite dilution, 20°C) (Kerr-McGee Bulletin)
Heat capacity	
Constant pressure (C_p)	126 J/(mole-°C) (25°C) (Lange's Handbook 1979)
Thermal conductivity	1.115 W/(m-°C) (0°C) (Lange's Handbook 1979)
pH of aqueous solution	7.0-9.5 (45 percent solution) (Erco PIM)
Electrical conductivity	6.2 ohm^{-1} m^{-1} (10 percent solution, 20°C), 13.4 ohm^{-1} m^{-1} (30 percent solution, 20°C), 15.7 ohm^{-1} m^{-1} (50 percent solution, 20°C) (Ullmann 1975)
Solubility	
In water	79.5 g/100 mL (0°C), 95.7 g/100 mL (20°C), 114.6 g/100 mL (40°C) (Linke 1965)
In other common materials	Soluble in ethanol, liquid ammonia and glycerin (CRC 1980)

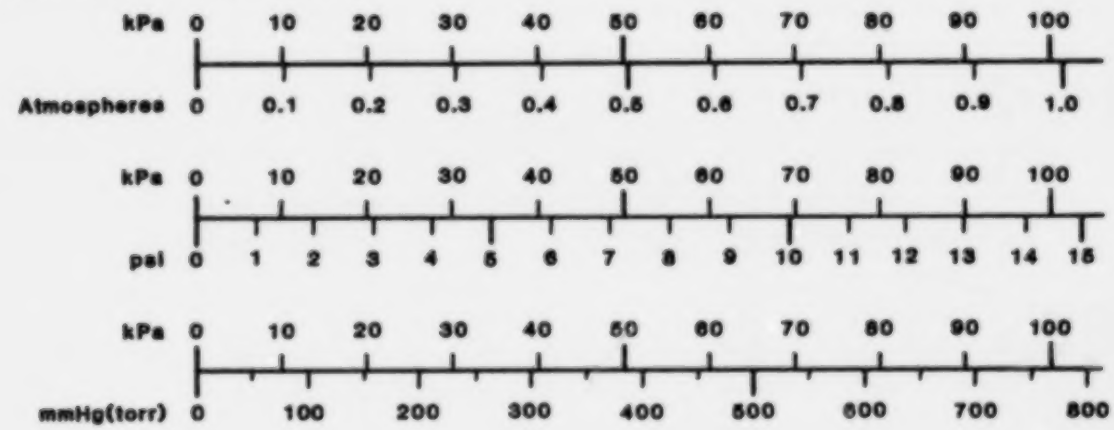
TABLE 1

SODIUM CHLORATE

CONVERSION NOMOGRAMS



Pressure 1 kPa = 1 000 Pa



Viscosity

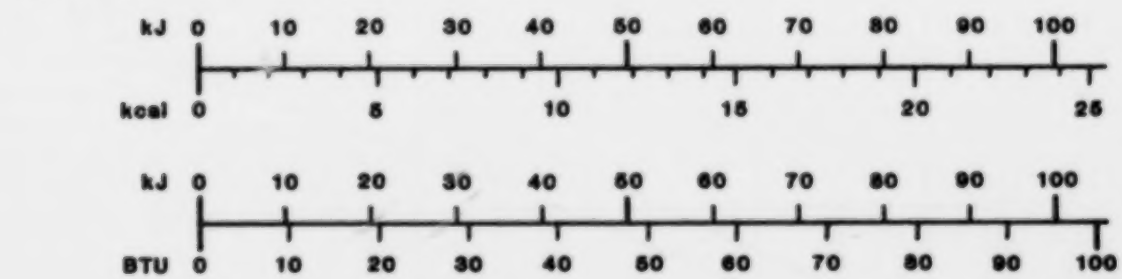
Dynamic 1 Pa·s = 1 000 centipoise (cP)

Kinematic 1 m^2/s = 1 000 000 centistokes (cSt)

Concentration (in water)

1 ppm ≅ 1 mg/L

Energy (heat) 1 kJ = 1 000 J



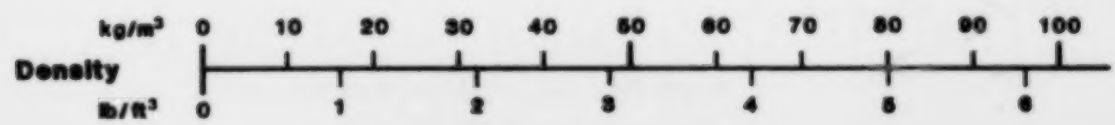


FIGURE 1

SODIUM CHLORATE

SOLUBILITY IN WATER

Reference: LINKE 1965

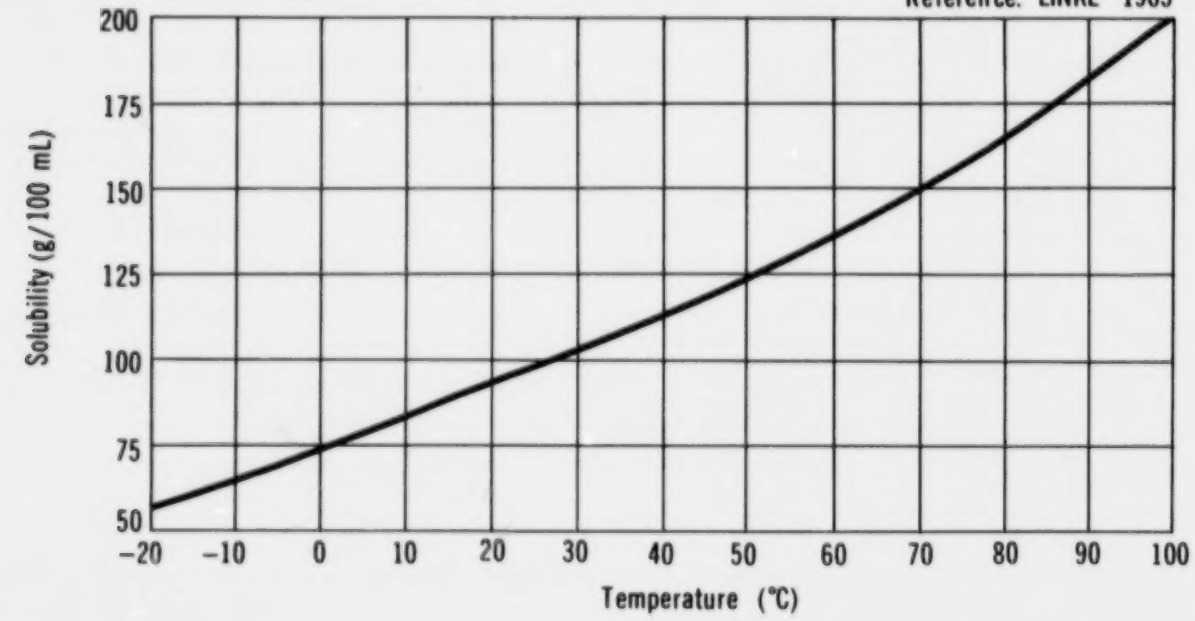
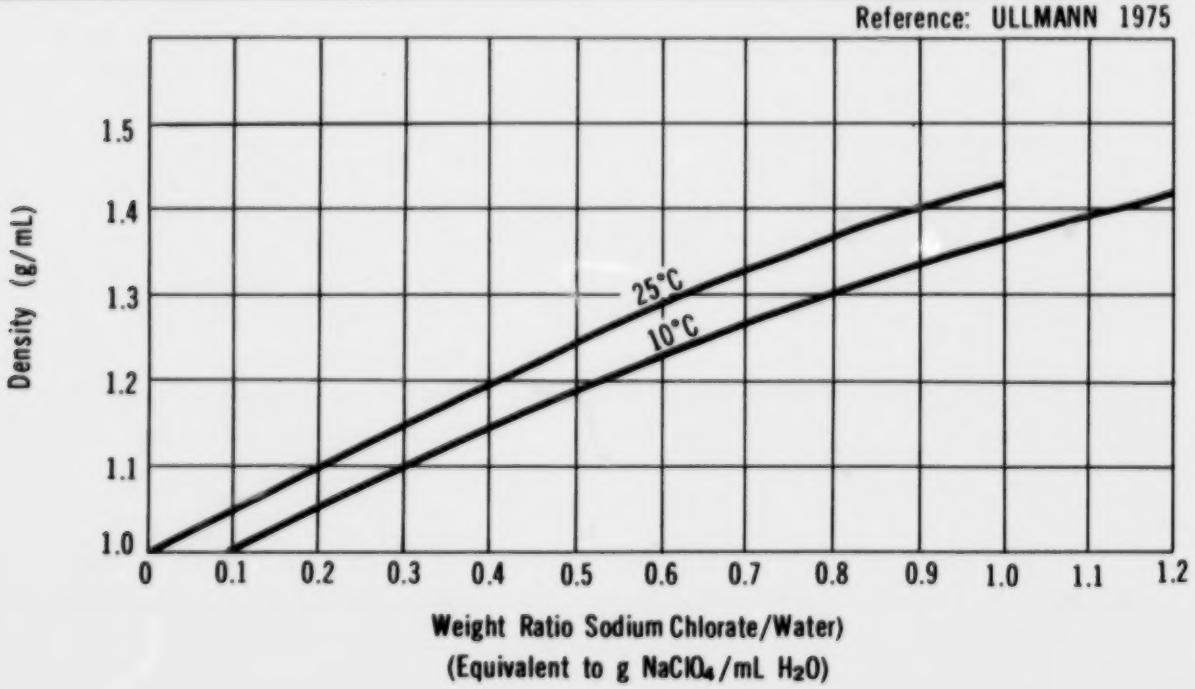


FIGURE 2

SODIUM CHLORATE (Solutions)

DENSITY OF SOLUTIONS

Reference: ULLMANN 1975



3 COMMERCE AND PRODUCTION

3.1 Grades, Purities (Erco PIM; Olin MSDS 1980; Hooker PIM; Kirk-Othmer 1979)

Sodium chlorate is sold either as a solid with purities ranging from 99 to 99.9 percent, or as a solution with purities of 25 to 46 percent sodium chlorate. A typical specification for the solid might be 99.5 percent $NaClO_3$, 0.12 percent maximum NaCl and 0.2 percent maximum water. Typical specifications for solutions might be 42 percent $NaClO_3$, 7 percent NaCl and 51 percent water; or 25.4 percent $NaClO_3$, 14.9 percent NaCl and 59.7 percent water. Customers may specify higher salt (NaCl) contents to suit their individual needs.

3.2 Domestic Manufacturers (Corpus 1984; CBG 1980; Scott 1979)

These are corporate headquarters' addresses and are not intended as spill response contacts.

B.C. Chemicals Ltd.
P.O. Box 6000
Prince George, British Columbia
V2N 2K3
(604) 563-0607

Canadian Occidental Petroleum Ltd.
Hooker Chemical Division
700 Fourth Avenue S.W.
1600 McFarlane Tower
Calgary, Alberta
T2P 0K2
(403) 265-2390

Erco Industries Ltd.
2 Gibbs Road
Islington, Ontario
M9B 1R1
(416) 239-7111

PPG Industries Canada Ltd.
5029 St. Ambroise Street
Montreal, Quebec
H4C 2E9
(514) 993-6721

Prince Albert Pulp Company Ltd.
Saskatoon Chemicals Division
P.O. Box 1586
Saskatoon, Saskatchewan
S7K 3R3
(306) 652-9456

QueNord Ltd.
P.O. Box 2000
1900 St. Patrice St. E.
Magog, Quebec
J1X 4X6
(819) 843-8771

St. Anne Chemical
8 Prince Arthur Avenue
Toronto, Ontario
M5R 1A9
(416) 968-2900

3.3 Other Suppliers (Corpus 1984; CBG 1980; Scott 1979)

Pennwalt of Canada Ltd.
700 Third Line
Oakville, Ontario
L6J 5A3
(416) 827-9841

Ugine-Kuhlmann of Canada Ltd.
2052 TransCanada Highway
Dorval, Quebec
H9P 2N4
(514) 683-8750

3.4 Major Transportation Routes

Current Canadian production of sodium chlorate is very widespread, occurring in seven provinces. The largest production facilities are in Buckingham, Beauharnois and Magog, Quebec (47 percent of total capacity) and in Vancouver, Prince George and Squamish, British Columbia (23 percent of total capacity). Other production facilities are located in Ontario, Manitoba, Saskatchewan and New Brunswick. The product is shipped in tank cars, tank trucks, or drums. Transportation is widespread across Canada.

3.5 Production Levels (Corpus 1984)

Company, Plant Location	Nameplate Capacity kilotonnes/yr (1984)
B.C. Chemicals, Prince George, B.C.	30
BCM Technologies, Amherstburg, Ont.	22.5
Canadian Occidental, Brandon, Man.	11
Canadian Occidental, Nanaimo, B.C.	7.5
Canadian Occidental, Squamish, B.C.	11
Erco Industries, Buckingham, Que.	71.5
Erco Industries, Vancouver, B.C.	54.5
Erco Industries, Thunder Bay, Ont.	46
QueNord, Magog, Que.	40
PPG Industries, Beauharnois, Que.	80
St. Anne Chemical, Nackawic, N.B.	10
Saskatoon Chemical, Saskatoon, Sask.	25
TOTAL	409
Domestic Production (1983)	294
Imports (1983)	2.5
TOTAL SUPPLY	296.5

3.6 Manufacture of Sodium Chlorate (FKC 1975; Kirk-Othmer 1979; CCPA 1983)

3.6.1 General. Sodium chlorate is manufactured by electrolysis of acidified sodium chloride brine.

3.6.2 Raw Materials. Raw materials used in the manufacture of sodium chlorate include sodium chloride and minor amounts of hydrochloric acid, water-treating agents and inhibitors.

3.6.3 Manufacturing Process. Sodium chloride is dissolved in softened water to form a saturated solution. Impurities such as calcium are removed by precipitation with sodium salts; the pH is adjusted to slightly over 7 with hydrochloric acid. A small amount of sodium dichromate is added to inhibit corrosion. The brine is then fed continuously to electrolysis cells. Older installations use graphite electrodes; however, metal electrodes are now becoming more popular. The overall reaction is:

$$NaCl + 3H_2O \xrightarrow{\text{electrolysis}} NaClO_3 + 3H_2$$

Hydrogen may be recovered.

The chlorate-rich solution is pumped from the cell and heated to 90°C to destroy residual hypochlorite. Insoluble impurities such as electrode mud settle out. The solution passes through multiple-effect evaporators to concentrate the sodium chlorate and precipitate the (less soluble) sodium chloride. The latter is recycled. The filtrate is cooled to 45°C or less (depending on water temperature) to precipitate sodium chlorate crystals which are centrifuged, washed, and dried. Wash liquors are recycled.

About 50 to 75 percent of each sodium chloride charge is converted to chlorate; since the unconverted sodium chloride is recycled, overall yield may be as high as 95 percent.

3.7 Major Uses in Canada (Corpus 1984)

Sodium chlorate is primarily used for pulp bleaching, herbicides and defoliants. In 1984, 64 percent of domestic production was used for pulp bleaching and 33 percent was exported.

3.8 Major Buyers in Canada (Corpus 1984)

Abitibi-Price, Smooth Rock Falls, Ont., Jonquière, Que.
Amok, Cluff Lake, Sask.
B.C. Forest Products, Crofton, Mackenzie, B.C.
B.C. Timber, Prince Rupert, Castlegar, B.C.
Boise-Cascade Canada, Ft. Frances, Ont.; Miramichi, N.B.

Canadian Cellulose, Prince Rupert, Castlegar, B.C.
CIP, La Tuque, Que.
Cdn. Forest Products, Pt. Mellon, B.C.
Cdn. International Paper, La Tuque, Que.
Cariboo Pulp, Quesnel, B.C.
Consolidated-Bathurst, Pontiac, Que.
Crestbrook Forest, Skookumchuk, B.C.
Crown Forest Ind., Campbell R., B.C.
Denison Mines, Elliot Lake, Ont.
Domtar, Quevillon, Que; Cornwall, Ont.
Donohue-St-Felicien, St. Felicien, Que.
Eddy Forest Products, Espanola, Ont.
Eldorado Nuclear, Rabbit Lake, Sask.
Fraser, Edmundston, Atholville, N.B.
Great Lakes Forest Products, Dryden, Thunder Bay, Ont.
Intercontinental Pulp, Prince George, B.C.
Iving Pulp & Paper, Saint John, N.B.
James River-Marathon, Marathon, Ont.
Kimberley-Clark, Terrace Bay, Ont.
MacMillan Bloedel, Harmac, B.C.
Madawaska Mines, Bancroft, Ont.
Northwood Pulp, Prince George, B.C.
Nova Scotia Forest Ind., Port Hawkesbury, N.S.
Prince Albert Pulp, Prince Albert, Sask.
Prince George Pulp, Prince George, B.C.
Proctor and Gamble Cellulose, Grand Prairie, Alta.
Rio Algom Mines, Elliot Lake, Ont.
St. Anne-Nackawic, Nackawic, N.B.
St. Regis Alberta, Hinton, Alta.
Scott Maritimes, New Glasgow, N.S.
Tahsis, Gold River, B.C.
Thurso Pulp & Paper, Thurso, Que.
Western Forest Products, Squamish, B.C.
Weyerhaeuser, Kamloops, B.C.

4 MATERIAL HANDLING AND COMPATIBILITY

4.1 Containers and Transportation Vessels

4.1.1 Bulk Shipment. Bulk solid is shipped by railway hopper cars or by highway vehicles. Bulk solutions are shipped in railway tank cars or in railway tank trucks.

4.1.1.1 Railway tank cars. Railway tankers used to transport sodium chlorate solutions are described in Table 2. Figure 3 shows a CTC/DOT 111A60W1 railway car used to transport sodium chlorate solutions; Table 3 indicates railway tank car details associated with this drawing. Figure 4 and Table 4 provide details on railway hopper cars such as would be used to transport solid sodium chlorate.

TABLE 2 RAILWAY TANK CAR SPECIFICATIONS

CTC/DOT* Specification Number	Description
111A60W1	Steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Safety valve (242 kPa) (35 psi) or safety vent (414 kPa) (60 psi). Bottom outlet or washout optional.
111A60W1 (1L)	Same as 111A60W1 except interior lined for sodium chlorate solutions greater than 10%.
103W	Steel fusion-welded tank with dome. Uninsulated or insulated. General service. 2% dome. Safety valves (242 kPa) (35 psi) or safety vent (414 kPa) (60 psi). Bottom outlet or washout optional (MCA 1952).

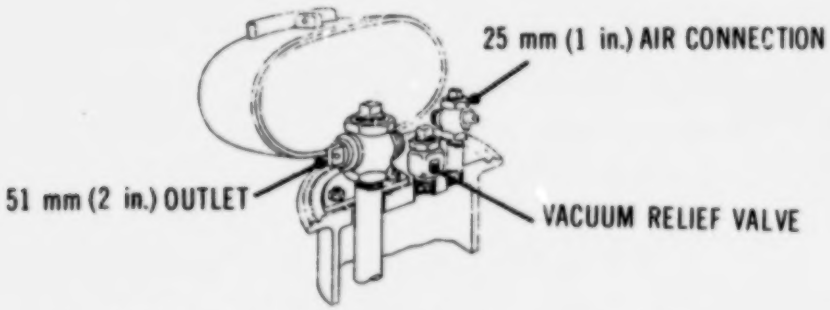
* Canadian Transport Commission and Department of Transportation (U.S.)

4.1.1.2 Highway vehicles. Solid sodium chlorate is also transported in bulk form in trailer tank trucks in capacities of about 18 tonnes. Each trailer is actually a sloping tank constructed of stainless steel, aluminum or fibreglass. The trailer has several hatches to make unloading easier and is equipped with a 100 mm (2.5 in.) flanged discharge connection (Erco PIM).

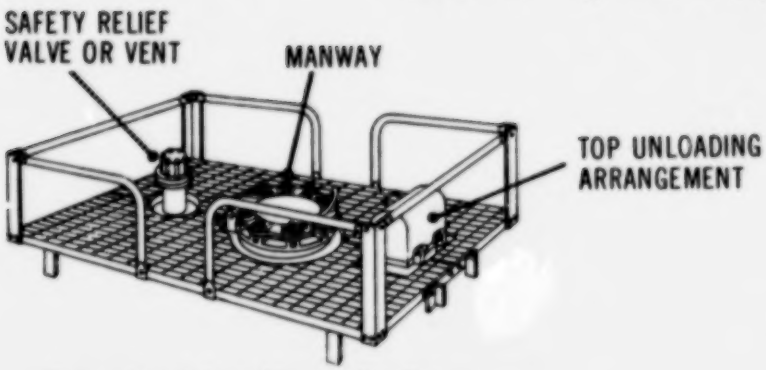
SODIUM CHLORATE

RAILWAY TANK CAR - CLASS 111A60W1

(Reference - TCM 1979; RTDCR 1974)



Detail of top unloading arrangement



Detail of loading platform

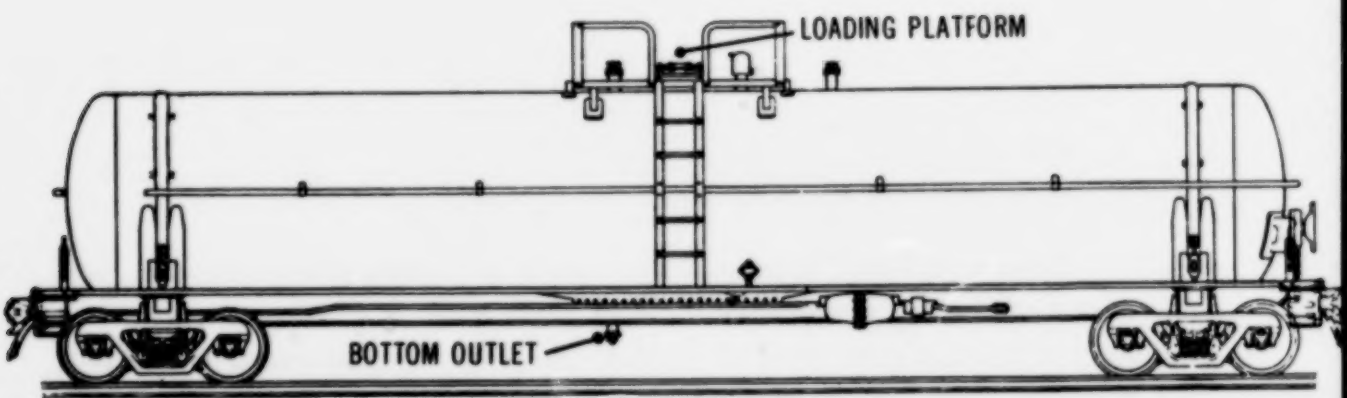


Illustration of tank car layout

TABLE 3 TYPICAL RAILWAY TANK CAR SPECIFICATIONS - CLASS 111A60W1 (TCM 1979; RTDCR 1974)

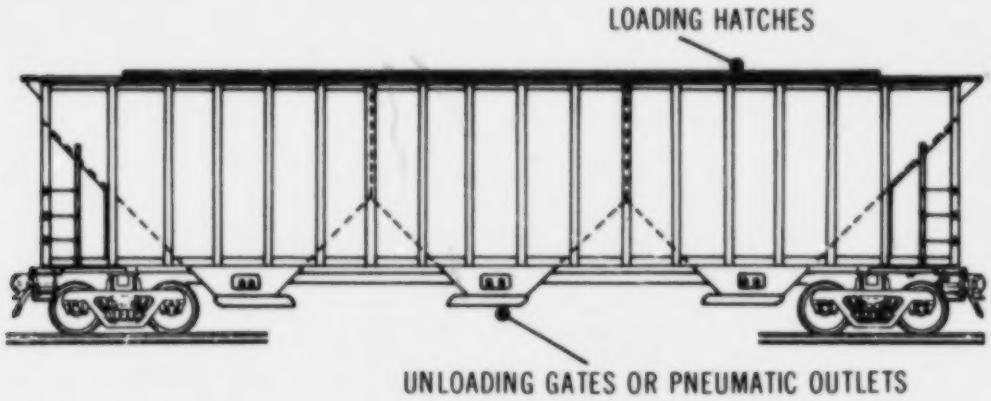
Description	Tank Car Size (Imp. Gal.) 16 700	17 200	20 000
Overall			
Nominal capacity	75 700 L (16 700 gal.)	78 000 L (17 200 gal.)	90 900 L (20 000 gal.)
Car weight- empty	33 900 kg (74 700 lb.)	33 900 kg (74 700 lb.)	38 900 kg (85 800 lb.)
Car weight- max.	119 000 kg (263 000 lb.)	119 000 kg (263 000 lb.)	119 000 kg (263 000 lb.)
Tank			
Material	Steel	Steel	Steel
Thickness	11.1 mm (7/16 in.)	11.1 mm (7/16 in.)	11.1 mm (7/16 in.)
Inside diameter	2.60 m (102 in.)	2.62 m (103 in.)	2.74 m (108 in.)
Test pressure	414 kPa (60 psi)	414 kPa (60 psi)	414 kPa (60 psi)
Burst pressure	1640 kPa (240 psi)	1640 kPa (240 psi)	1640 kPa (240 psi)
Approximate Dimensions			
Coupled length	17 m (57 ft.)	17 m (57 ft.)	18 m (60 ft.)
Length over strikers	16 m (53 ft.)	16 m (53 ft.)	17 m (57 ft.)
Length of truck centres	13 m (42 ft.)	13 m (42 ft.)	14 m (45 ft.)
Height to top of grating	4 m (12 ft.)	4 m (12 ft.)	4 m (13 ft.)
Overall height	5 m (15 ft.)	5 m (15 ft.)	5 m (15 ft.)
Overall width (over grabs)	3.2 m (127 in.)	3.2 m (127 in.)	3.2 m (127 in.)
Length of grating	2-3 m (8-10 ft.)	2-3 m (8-10 ft.)	2-3 m (8-10 ft.)
Width of grating	1.5-2 m (5-6 ft.)	1.5-2 m (5-6 ft.)	1.5-2 m (5-6 ft.)
Loading/Unloading Fixtures			
Top Unloading			
Unloading connection	51 mm (2 in.)	51 mm (2 in.)	51 mm (2 in.)
Manway/fill hole	>406 mm (>16 in.)	>406 mm (>16 in.)	>406 mm (>16 in.)
Air connection	25-51 mm (1-2 in.)	25-51 mm (1-2 in.)	25-51 mm (1-2 in.)
Bottom Unloading			
Bottom outlet	102-152 mm (4-6 in.)	102-152 mm (4-6 in.)	102-152 mm (4-6 in.)
Safety Devices	Safety vent or valve		
Dome	None		
Insulation	Optional		

FIGURE 4

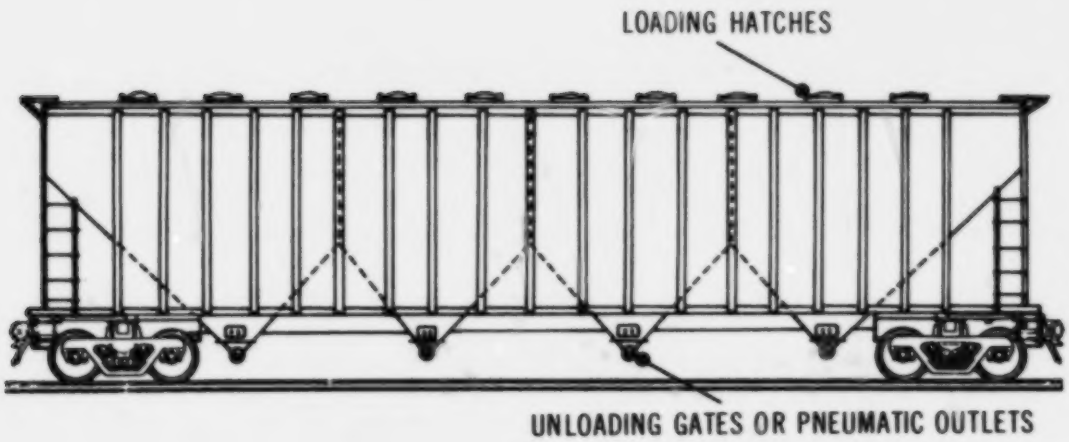
SODIUM CHLORATE

COVERED HOPPER CARS - AAR CLASS LO

(Reference - CLC 1974, AAR 1983)



Typical 3 - Compartment Hopper Car



Typical 4 - Compartment Hopper Car

TABLE 4 TYPICAL RAILWAY HOPPER CAR SPECIFICATIONS - AAR CLASS LO (CLC 1974)

Description	Hopper Car Size (cu. ft.) 5800		Hopper Car Size (cu. ft.) 4700	
Overall				
Nominal capacity	164 m^3	(5800 cu. ft.)	133 m^3	(4700 cu. ft.)
Weight capacity	86 000 kg	(190 000 lb.)	89 000 kg	(196 000 lb.)
Car weight - empty	45 000 kg	(100 000 lb.)	45 000 kg	(100 000 lb.)
Car weight - max.	119 000 kg	(263 000 lb.)	119 000 kg	(163 000 lb.)
Hopper/Compartments				
Number	4		3	
Material	Steel		Steel	
Inside length (typical)	410 cm	(160 in.)	460 cm	(180 in.)
Inside width (typical)	300 cm	(118 in.)	300 cm	(118 in.)
Spacing between outlets	4 m	(13 ft.)	5 m	(15 ft.)
Slope angle	40-45°		40-45°	
Approximate Dimensions				
Coupled length	21 m	(68 ft.)	18 m	(60 ft.)
Length over strikers	20 m	(65 ft.)	17 m	(57 ft.)
Length of truck centres	16 m	(54 ft.)	14 m	(46 ft.)
Clearance height	5 m	(15 ft.)	5 m	(15 ft.)
Height to top of running board	5 m	(15 ft.)	4 m	(14 ft.)
Overall width	3.1 m	(123 in.)	3.2 m	(126 in.)
Inside length	19 m	(63 ft.)	17 m	(55 ft.)
Loading/Unloading Fixtures				
Loading Hatches:	Cars typically equipped with 4 to 12 loading hatches. Typical dimensions of these are 36-61 cm (14-24 in.) in diameter or square dimensions.			
Unloading Fixtures:	Equipped with unloading gates at bottom of 36-61 cm (14-24 in.) square and/or pneumatic unloading connections of 10-20 cm (4-8 in.) in diameter.			

Insulated MC311 and MC312 tankers are generally utilized. Both classes are covered under the Transport Canada TC312 specifications. Such specifications require that cargo tanks unloaded by pressure in excess of 104 kPa (15 psi) be designed and constructed in accordance with the ASME Code (TDGC 1980).

4.1.2 Packaging. In addition to bulk shipments, sodium chlorate in solid form is also shipped in drums fabricated from a variety of construction materials (TDGC 1980). A

description of these drums is contained in Table 5. Polypropylene bags with a capacity of 1 tonne are also used (CCPA 1983).

TABLE 5 DRUMS

Type of Drum	Designation	Description	Figure No. (If Any)
Steel	1A1	Nonremovable head, reusable	5
	1A1A	1A1 with reinforced chime	5
	1A1B	1A1 with welded closure	5
	1A1C	1A1 with lead coating	5
	1A1D	1A1 with other coating	5
	1A2	Removable head, reusable	5
	1A2A	1A2 with reinforced chime	5
	1A2B	1A2 with coating other than lead	5
	1A3	Nonremovable head, single use	5
	1A4	Removable head, single use	5
Steel with inner plastic receptacles	6HA1	Outer steel sheet drum. Inner plastic receptacle. Maximum capacity 225 L (50 gal.)	
Fibreboard with inner plastic receptacles	6HG1	Outer container of convolutely wound plies of fibreboard. Inner plastic in shape of drum. Maximum capacity of 225 L (50 gal.)	

4.2 Off-loading

4.2.1 Off-loading Equipment and Procedures for Railway Cars and Highway Vehicles. Sodium chlorate solutions are usually unloaded from a bottom outlet using pumps (CCPA 1983). Proceed with bottom off-loading as indicated below (HSC 1977):

- Connect the unloading line to a bottom outlet and open the bottom valve.
- Open the top valve to permit air entry.
- Off-load the car by pump.

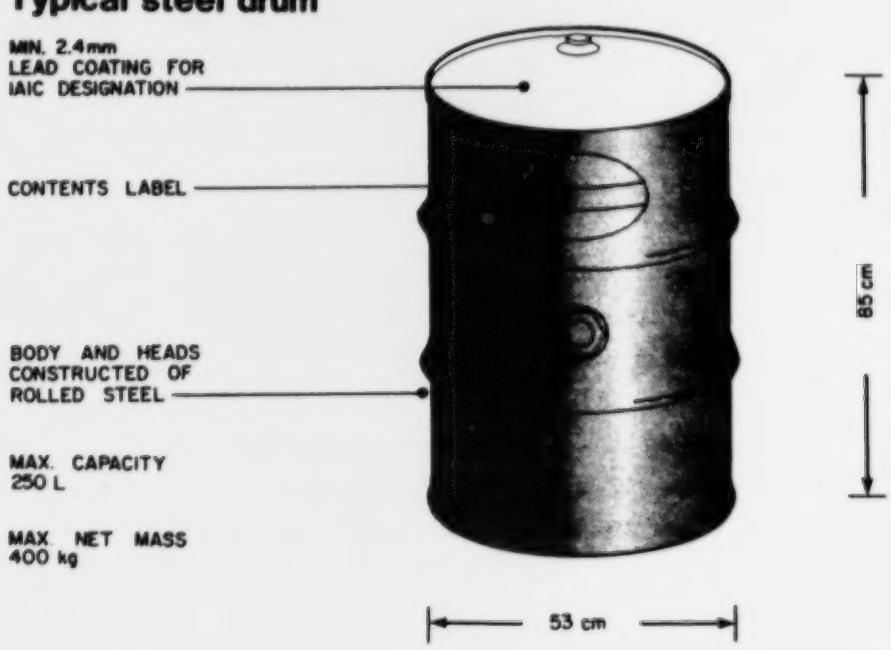
When unloading solid material from hopper cars or trucks, the following procedure must be followed (Erco PIM; CCPA 1983):

- Water should be heated to 85°C prior to the arrival of the hopper vehicle.
- Incorporate a recirculating pump in the unloading system to ensure good flow is available and recirculating to the storage tank.
- Open the top hatch of the hopper.

FIGURE 5

SODIUM CHLORATE

TYPICAL DRUM CONTAINER



- Use the recirculating pump to fill up the boot at the bottom of the hopper car by means of a sparger line connected to the pump discharge.
- Once the boot portion of the hopper is flooded, turn on the unloading pump. Continue unloading until the car is empty.
- After unloading, wash out the last traces of the solid and hose off the outside of the car.
- Backflush the unloading line and sparger line to prevent internal crystallization.

4.2.2 Specifications and Materials for Off-loading Equipment (Solution). Pipes up to 19 mm (3/4 in.) in diameter should be Schedule 40 stainless steel; 25 mm (1 in.) and up should be Schedule 10 or stainless 316 L. Flanged or welded joints should be used especially for pipe diameters of 63 mm (2.5 in.) or larger (HSC 1977). The unloading line is usually 51 mm (2 in.) pipe to suit standard discharge fittings on rail cars. FRP (fibre-reinforced plastic) is recommended for permanent installations; carbon steel can be used for short-term or intermittent service but should be drained or flushed after use (CCPA 1983).

Flexible bellows-type expansion joints may be used for the flexible sections of the unloading line. They are manufactured with ASA ductile iron flanges with expansion member molded from tetrafluoroethylene resin (Dow PPS 1972). Flexible hose to rail cars or trucks should be specially treated reinforced rubber (Erco PIM).

Diaphragm valves of cast iron bodies lined with chlorinated polyether or polyvinylidene chloride resin will serve adequately (DPLV 1972). Chlorosulphonated polyethylene resin is an adequate gasket material in this service (DPLP 1972). In stainless steel systems, gate valves of the single disc outside stem and yoke type are preferred (HSC 1977).

All-iron centrifugal pumps can be used. A stainless steel or Monel body and impeller should be used for salted sodium chlorate. Teflon water seals are suitable (HSC 1977). Glandless pumps or water-purged mechanical seals of noncombustible construction are recommended (CCPA 1983).

The unloading tank should be designed at least 20 percent beyond the desired capacity. Normal capacity is about 90 000 L (Erco PIM). The tank should contain a heating coil of Monel or titanium and should be insulated and clad. The coil should be designed to maintain a solution temperature of 49°C. The liquid level in the tank should be monitored by a level indication system (Erco PIM). FRP or tile-lined steel are recommended for construction of the tanks. A type 316 stainless steel top-mounted agitator in the tank is also desirable (HSC 1977).

On stainless steel piping systems, Teflon gaskets of 2 or 3 mm are preferred; when employing an aluminum or FRP piping arrangement, Teflon or Hypalon should be used (HSC 1977). Generally Teflon, Viton, Hypalon or Tygon gaskets are recommended for stainless steel piping (CCPA 1983).

4.3 Compatibility with Materials of Construction

The compatibility of sodium chlorate with materials of construction is indicated in Table 6. The unbracketed abbreviations are described in Table 7. The rating system is briefly described below:

Recommended:	This material will perform satisfactorily in the given application.
Conditional:	Material will show deterioration in the given application; however, it may be suitable for intermittent or short-term service.
Not Recommended:	Material will be severely affected in this application and should not be used.

TABLE 6 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
1. Pipes and Fittings	Most	23		PVC I PVC II (DPPED 1967)	
		60		PVC I (DPPED 1967)	PVC II (DPPED 1967)
		66	Chlorinated Polyether PVDC (DCRG 1978)		
		107	PP (DCRG 1978)		
		135	PVDF (DCRG 1978)		
		To operating limit of material		PVC I* ABS PE (MWPP 1978)	
	Most	To boiling	SS 316 ELC FRP (HSC 1977)	CS (HSC 1977)	Aluminum (CCPA 1983)
	Most	Low	Aluminum (CCPA)		
2. Valves	10 or 25%	21	SS J-20 SS 316 (JSSV 1979) SS 304 ELC (HSC 1977)		
3. Pumps	50%	82	GRP with FPM A "O" ring Monel body and impeller (Erco PIM)		
	Aqueous Solution	Most	SS 304 SS 316 High Silicon Cast Iron (HIS 1969)		

TABLE 6 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
4. Storage	Most	Most	CS with tile-lining FRP SS (HSC 1977) Monel (CCPA 1983)		
5. Others	Up to 10% (Aqueous)	60	PE PP POM IIR EPDM CR FPM CSM (GF)	uPVC NBR (GF)	NR (GF)
	10 or 25%	20	SS 302 SS 304 SS 316 SS 430 (ASS)	SS 410 (ASS)	
	Saturated	60	uPVC PE PP POM IIR EPDM CR FPM CSM (GF)		NR NBR (GF)
		100	CSM (GF)	PP FPM (GF)	uPVC PE POM NR NBR IIR EPDM CR (GF)
		60	PVC (TPS 1978)		
		82	PP (TPS 1978)		
		85	CPVC (TPS 1978)		

TABLE 6 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
5. Other (cont'd)	Saturated	121	PVDF (TPS 1978) SBR (GPP)		
	10 to 30%	24 to 100	Glass (CDS 1967)		
	100%	24	Glass (CDS 1967)		
	10 to 30%	24	Concrete (CDS 1967)		
	100%	24	Concrete		Wood (CCPA 1983)

TABLE 7 MATERIALS OF CONSTRUCTION

Abbreviation	Material of Construction
ABS	Acrylonitrile Butadiene Styrene
	Aluminum
	Cast Iron, High Silicon
	Chlorinated Polyether
CPVC	Chlorinated Polyvinyl Chloride
CR	Polychloroprene (Neoprene)
CS	Carbon Steel
CSM	Chlorosulphonated Polyethylene (Hypalon)
	Concrete
EPDM	Ethylene Propylene Rubber
FPM	Fluorine Rubber (Viton)
FRP	Fibre Reinforced Plastic
GRP	Glass Reinforced Vinyl Ester
	Glass
	Iron
IIR	Isobutylene/Isoprene (Butyl) Rubber

TABLE 7 MATERIALS OF CONSTRUCTION (Cont'd)

Abbreviation	Material of Construction
NBR	Acrylonitrile/Butadiene (Nitrile, Buna N) Rubber
NR	Natural Rubber
	Nickel-Copper Alloy (Monel)
PE	Polyethylene
POM	Polyoxymethylene
PP	Polypropylene
PTFE	Polytetrafluoroethylene (Teflon)
PVC (followed by grade if any)	Polyvinyl Chloride
PVDC	Polyvinylidene Chloride
PVDF	Polyvinylidene Fluoride
SBR	Styrene/Butadiene (GR-5, Buna S) Rubber
SS (followed by grade)	Stainless Steel
uPVC	Unplasticized Polyvinyl Chloride
	Wood (Fir)

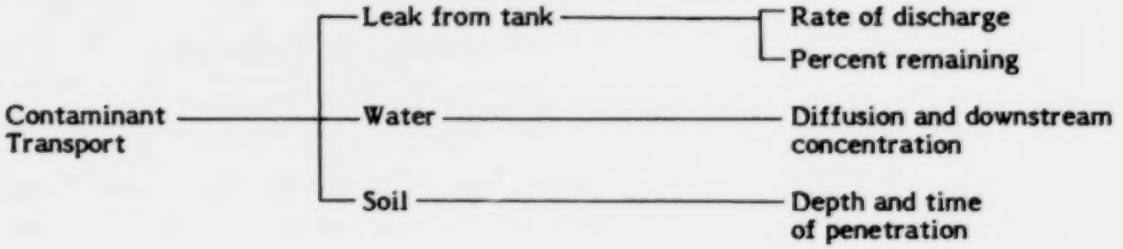
5 CONTAMINANT TRANSPORT

5.1 General Summary

Sodium chlorate is commonly transported as a solid in covered hopper cars or as an aqueous solution in tankers. When spilled in water, all forms will dissolve rapidly. When spilled on soil, the solution forms will spread on the surface and penetrate into the soil at a rate dependent on the soil type and its water content. Movement of sodium chlorate toward the water table may be an environmental problem.

Because sodium chlorate is essentially nonvolatile, vapour dispersion in air is not a problem. Dusting of sodium chlorate could be a severe problem in some spill situations; however, this is difficult to model and will not be covered in this manual.

The following factors are considered for the transport of sodium chlorate in water and soil:



It is important to note that, because of the approximate nature of the contaminant transport calculations, the approach adopted throughout has been to use conservative estimates of critical parameters so that predictions are approaching worst case scenarios for each medium. This may require that the assumptions made for each medium be quite different. As well as producing worst case scenarios, this approach allows comparison of the behaviours of different chemicals under the same assumptions.

5.2 Leak Nomograms

5.2.1 Introduction. Sodium chlorate solutions are transported in railway tank cars. While the capacities of the tank cars vary widely, one tank car has been chosen throughout the EnviroTips series for development of the leak nomograms. It is approximately 2.75 m in diameter and 13.4 m long, with a carrying capacity of about 80 000 L.

The aim of the nomograms is to provide a simple means to obtain the time history of the conditions in the tank car and the leak rate of the liquid. Because of the low volatility of sodium chlorate solution and the fact that tank cars are not pressurized, no leak nomograms have been prepared for vapour release from a puncture in the top of the tank.

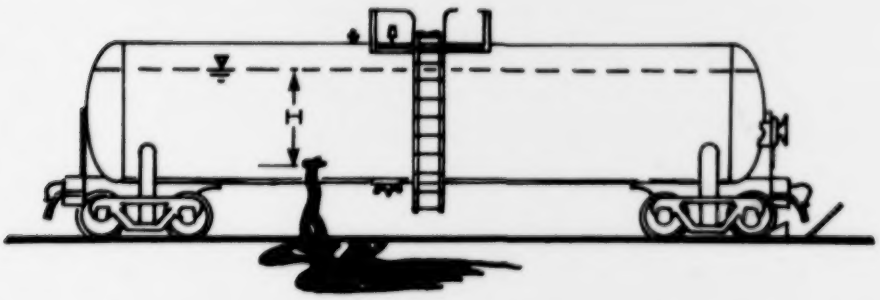


FIGURE 6 TANK CAR WITH PUNCTURE HOLE IN BOTTOM

5.2.2 Nomograms.

5.2.2.1 Figure 7: Percent remaining versus time. Figure 7 provides a means of estimating the percent of liquid remaining in the standard tank car after the time of puncture for a number of different hole diameters. The hole diameter is actually an equivalent diameter and can be applied to a noncircular puncture.

The standard tank car is assumed to be initially full (at t=0) with a volume of about 80 000 L of sodium chlorate solution. The amount remaining at any time (t) is not only a function of the discharge rate over time, but also of the size and shape of the tank car.

5.2.2.2 Figure 8: Discharge rate versus time. Figure 8 provides a means of estimating the instantaneous discharge rate (L/s) at any time (t) after the time of puncture for a number of equivalent hole diameters. The nomogram is only applicable to the standard tank car size with an initial volume of 80 000 L.

FIGURE 7

SODIUM CHLORATE

PERCENT REMAINING VS TIME

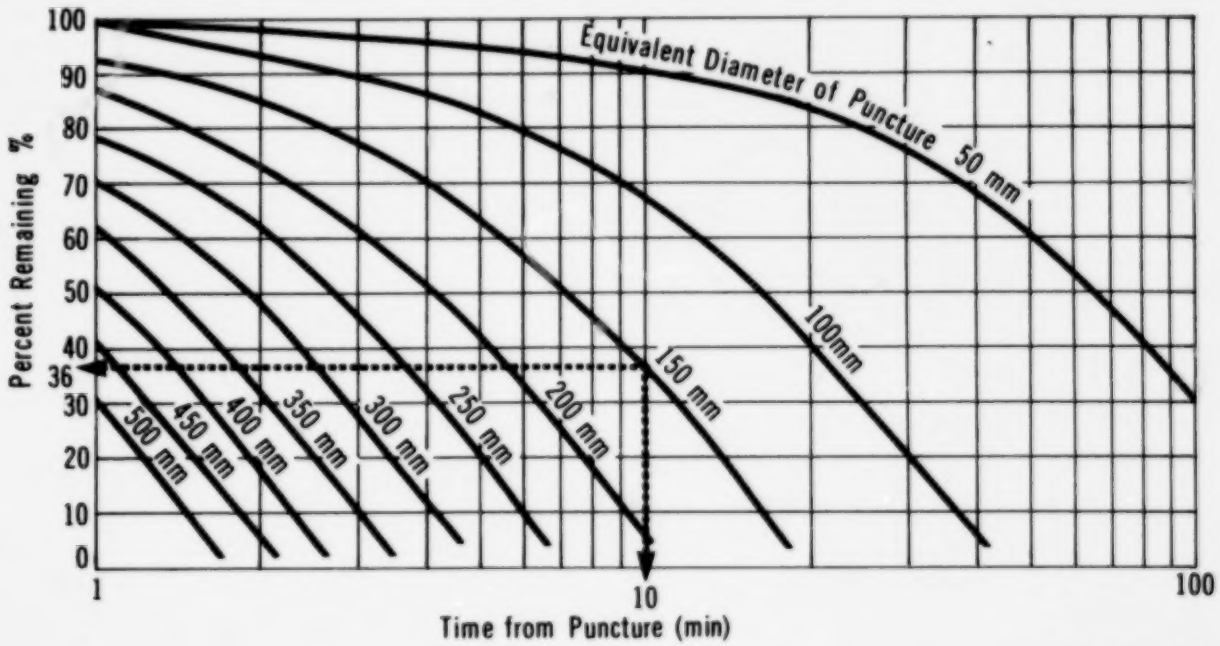
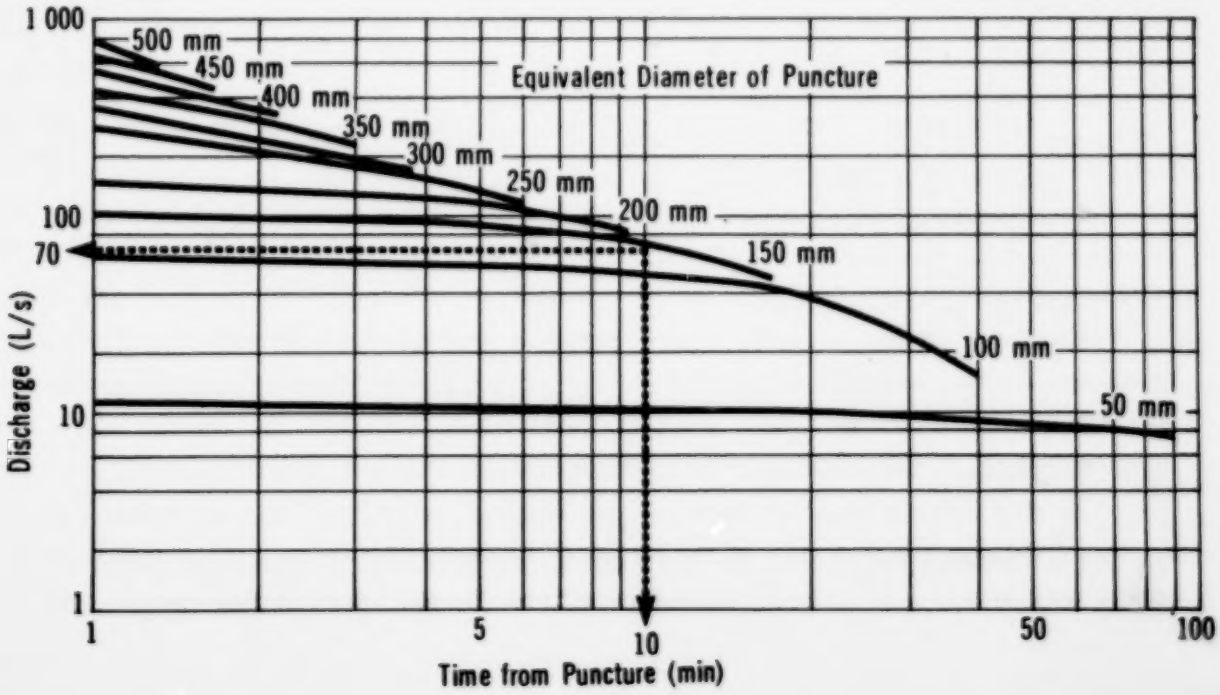


FIGURE 8

SODIUM CHLORATE

DISCHARGE RATE VS TIME



5.2.3 Sample Calculations.

i) Problem A

The standard tank car filled with a 30 percent aqueous solution of sodium chlorate has been punctured on the bottom. The equivalent diameter of the hole is 150 mm. What percent of the initial 80 000 L remains after 10 minutes?

Solution to Problem A

Use Figure 7

With t = 10 min and d = 150 mm, the amount remaining is about 36 percent or 28 800 L

ii) Problem B

With the same conditions as Problem A, what is the instantaneous discharge rate from the tank 10 minutes after the accident?

Solution to Problem B

Use Figure 8

With t = 10 min and d = 150 mm, the instantaneous discharge rate (q) = 70 L/s

5.3 Dispersion in the Air

Because sodium chlorate is nonvolatile in foreseeable spill circumstances, there is no significant potential for dispersion in air.

5.4 Behaviour in Water

5.4.1 Introduction. Sodium chlorate is very soluble in water. When spilled on a water surface, it will sink and dissolve rapidly. Mixing takes place and the spill is diluted. This mixing can generally be described by classical diffusion equations with one or more diffusion coefficients. In rivers, the principal mixing agent is stream turbulence, while in calm water mixing takes place by molecular diffusion.

To estimate pollutant concentration in a river downstream from a spill, the turbulent diffusion has been modelled. The model employed is strictly applicable to neutrally buoyant liquids and solids that dissolve in water. As sodium chlorate is denser than water, initially the maximum concentration would be expected near the bottom.

The one-dimensional model uses an idealized rectangular channel section and assumes a uniform concentration of the pollutant throughout the section. Obviously, this applies only to points sufficiently far downstream of the spill where mixing and dilution

have distributed the pollutant across the entire river channel. The model is applicable to rivers where the ratio of width to depth is less than 100 (W/d <100) and assumes a Manning's roughness coefficient of 0.03. Details of the model are outlined in the Introduction Manual.

No modelling has been carried out for molecular diffusion in still water. Rather, nomograms have been prepared to define the hazard zone and the average concentration within the hazard zone as a function of spill size, but independent of time.

5.4.2 Nomograms. The following nomograms are presented to calculate pollutant concentrations in non-tidal rivers and in lakes (still water).

Non-tidal Rivers

Figure 10: time versus distance for a range of average stream velocities

Figure 11: hydraulic radius versus channel width for a range of stream depths

Figure 12: diffusion coefficient versus hydraulic radius for a range of average stream velocities

Figure 13: alpha* versus diffusion coefficient for various time intervals

Figure 14: alpha versus delta* for a range of spill sizes

Figure 15: maximum concentration versus delta for a range of river cross-sectional areas

Lakes or Still Water Bodies

Figure 16: volume versus radius for the hazard zone for a range of lake depths

Figure 17: average concentration versus volume for the hazard zone for a range of spill sizes

The flowchart in Figure 9 outlines the steps required to estimate the downstream concentration after a spill and identifies the nomograms to be used. These nomograms (Figures 10 through 17) are described in the following subsections.

5.4.2.1 Nomograms for non-tidal rivers.

Figure 10: Time versus distance. Figure 10 presents a simple relationship between average stream velocity, time, and distance. Using an estimate of average stream velocity (U), the time (t) to reach any point of interest, at some distance (X) downstream of the spill, can be readily obtained from Figure 10.

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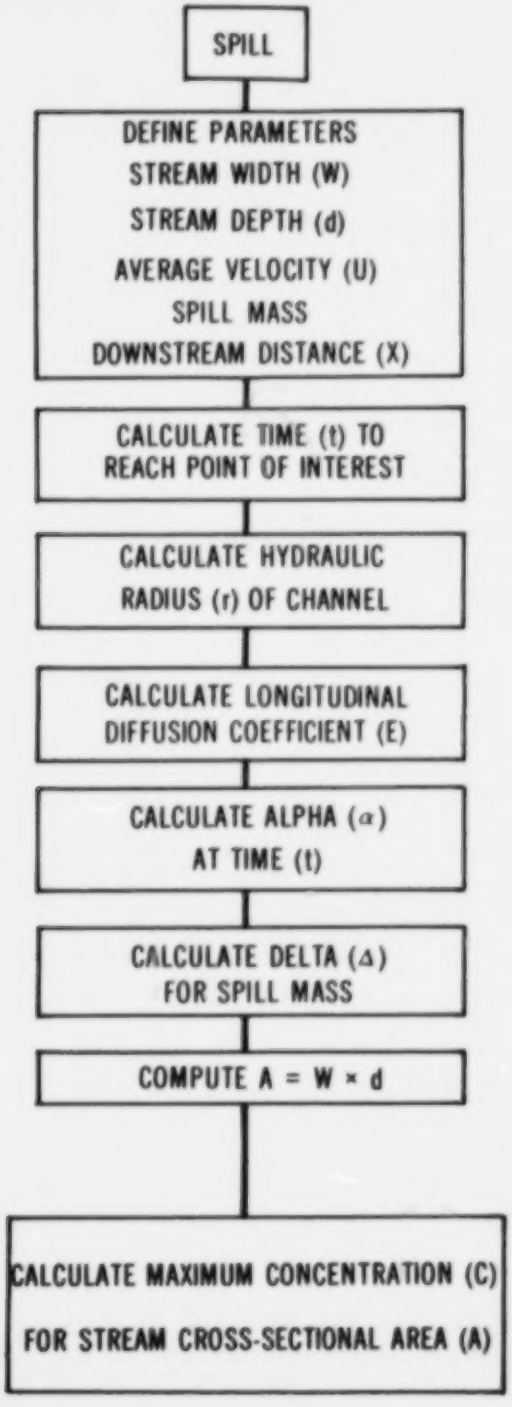
* Alpha and delta are conversion factors only and are of no significance other than to facilitate calulation of downstream concentration.

FIGURE 9

SODIUM CHLORATE

FLOW CHART TO DETERMINE POLLUTANT CONCENTRATION IN NON-TIDAL RIVERS


SPILL
DEFINE PARAMETERS
STREAM WIDTH (W)
STREAM DEPTH (d)
AVERAGE VELOCITY (U)
SPILL MASS
DOWNSTREAM DISTANCE (X)
CALCULATE TIME (t) TO REACH POINT OF INTEREST
CALCULATE HYDRAULIC RADIUS (r) OF CHANNEL
CALCULATE LONGITUDINAL DIFFUSION COEFFICIENT (E)
CALCULATE ALPHA (α) AT TIME (t)
CALCULATE DELTA (Δ) FOR SPILL MASS
COMPUTE A = W × d
CALCULATE MAXIMUM CONCENTRATION (C) FOR STREAM CROSS-SECTIONAL AREA (A)

Step 1: Observed or Estimated

W = _____ m

d = _____ m

U = _____ m/s

MASS = _____ tonnes

X = _____ m

Step 2: Use Figure 10

t = _____ minutes

Step 3: Use Figure 11

r = _____ m

Step 4: Use Figure 12

E = _____ m^2/s

Step 5: Use Figure 13

α = _____

Step 6: Use Figure 14

Δ = _____

Step 7: Compute stream cross-sectional Area (A)

A = W × d _____ m^2

Step 8: Use Figure 15

C = _____ ppm

FIGURE 10

SODIUM CHLORATE

TIME vs DISTANCE

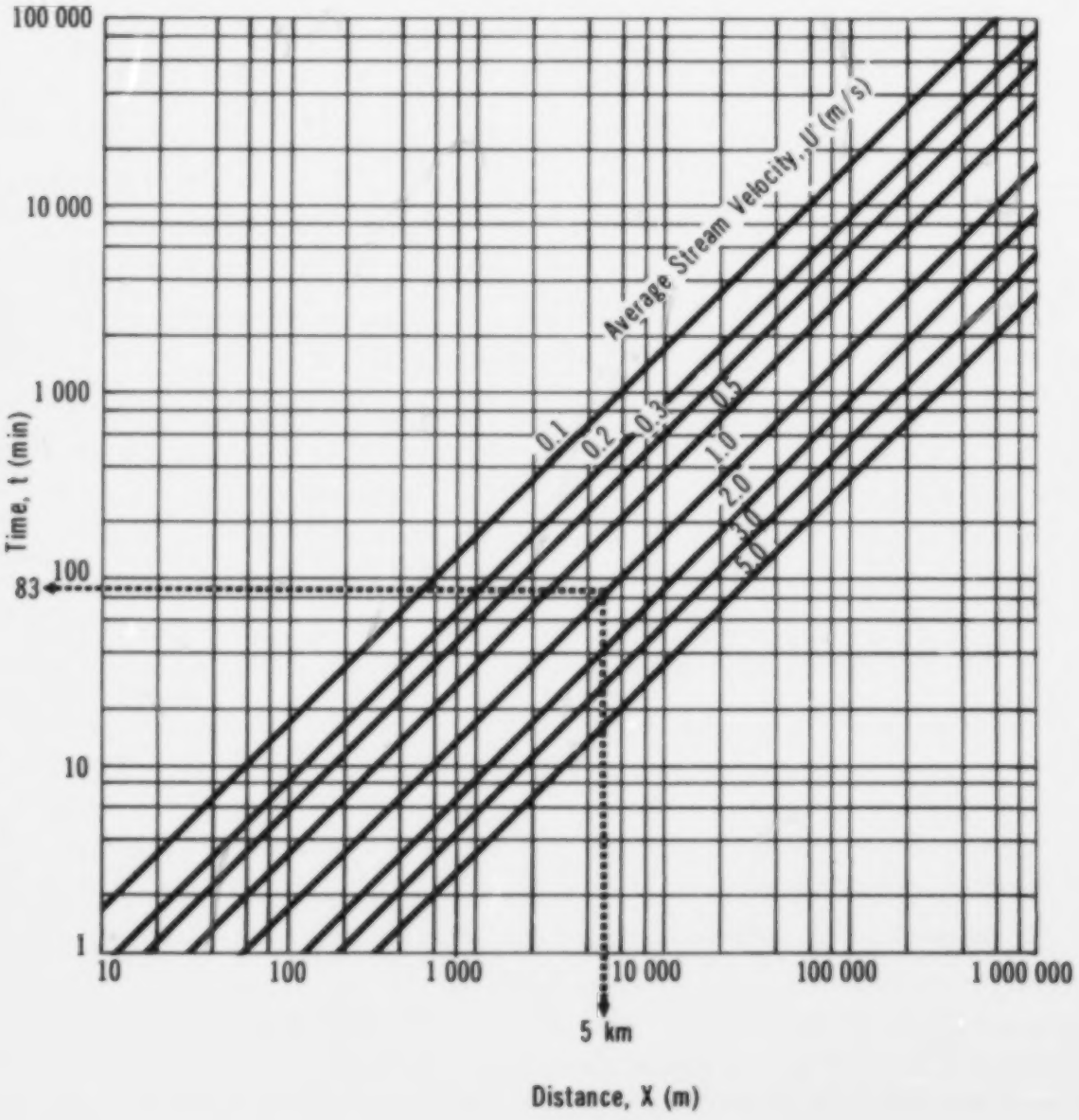


Figure 11: Hydraulic radius versus channel width. The model used to estimate downstream pollutant concentration is based on an idealized rectangular channel of width (W) and depth (d). The hydraulic radius (r) for the channel is required in order to estimate the longitudinal diffusion coefficient (E). The hydraulic radius (r) is defined as the stream cross-sectional area (A) divided by the wetted perimeter (P). Figure 11 is a nomogram for computation of the hydraulic radius (r) using the width and depth of the idealized river cross-section.

Figure 12: Diffusion coefficient versus hydraulic radius. Figure 12 permits calculation of the longitudinal diffusion coefficient (E), knowing the hydraulic radius (r) from Figure 11 and the average stream velocity (U).

Figure 13: Alpha versus diffusion coefficient. Figure 13 is used to estimate a conversion factor, alpha (α), which is a function of the diffusion coefficient (E) and the time (t) to reach the point of interest downstream of the spill.

Figure 14: Alpha versus delta. A second conversion factor, delta (Δ), must be estimated from Figure 14 to allow determination of the pollutant concentration at the point of interest. Delta (Δ) is a function of alpha (α) and the spill size.

Figure 15: Maximum concentration versus delta. Figure 15 represents the final step for calculation of the maximum downstream pollutant concentration (C) at the point of interest. Using the factor delta (Δ) and knowing the stream cross-sectional area (A), the concentration (C) is readily obtained from the nomogram. The value obtained from Figure 15 applies to neutrally buoyant liquids or solids and will vary somewhat for other pollutants which are heavier or lighter than water.

5.4.2.2 Nomograms for lakes or still water bodies.

Figure 16: Volume versus radius. The spill of a neutrally buoyant liquid in a lake in the absence of wind and current has been idealized as a cylinder of radius (r) and length (d), equivalent to the depth of the lake at the point of spill. The volume of water in the cylinder can be obtained from Figure 16. The radius (r) represents the distance from the spill to the point of interest.

Figure 17: Average concentration versus volume. For a known volume of water (within the idealized cylinder of radius (r) and length (d)), the average concentration of pollutant (C) can be obtained from Figure 17 for a known mass of spill. This assumes the pollutant is spread evenly throughout the cylinder. For pollutants that are more or less dense than water, the actual concentration at the bottom would be higher or lower, respectively.

FIGURE 11

SODIUM CHLORATE

HYDRAULIC RADIUS VS CHANNEL WIDTH

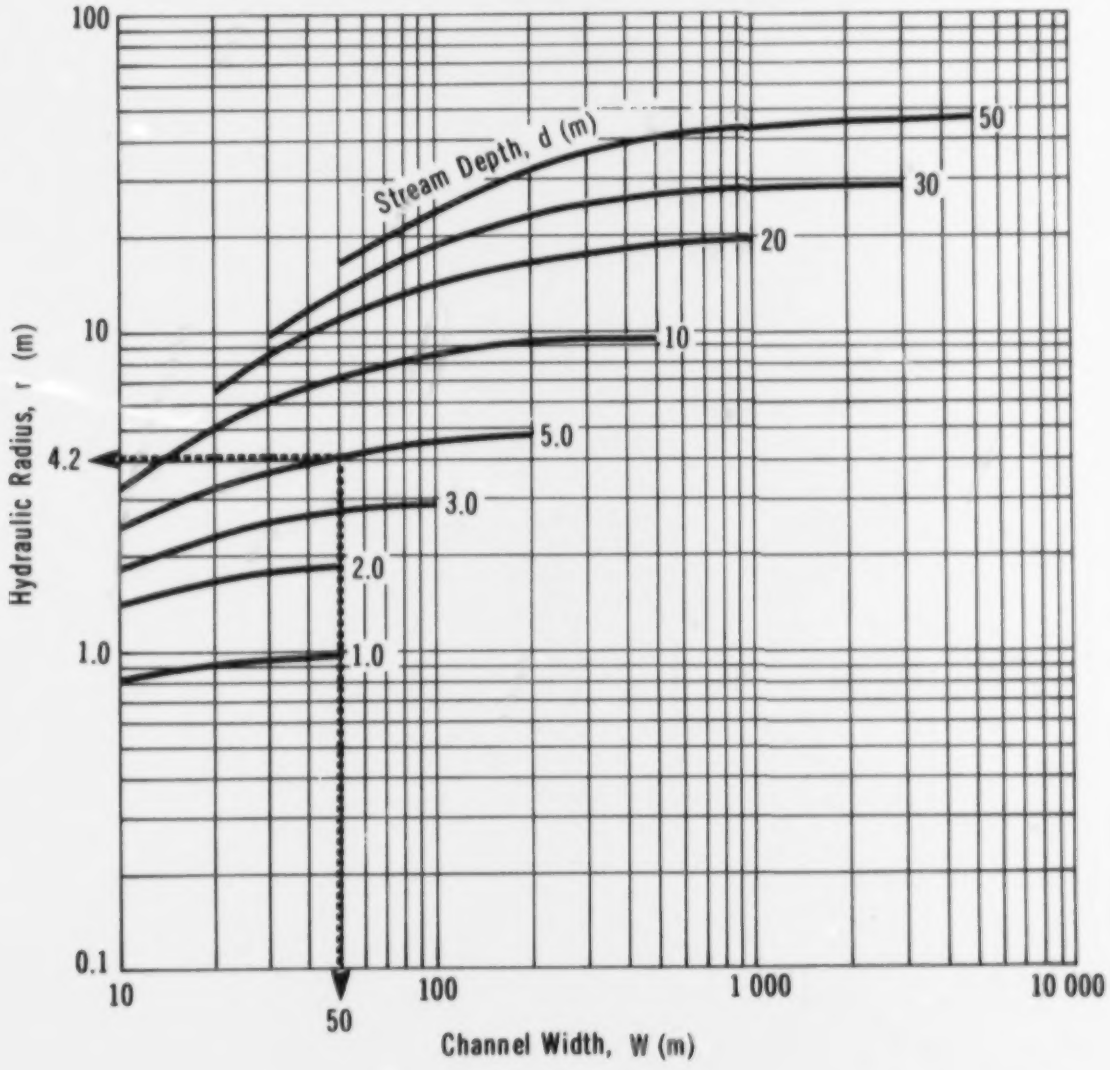


FIGURE 12

SODIUM CHLORATE

DIFFUSION COEFFICIENT
VS HYDRAULIC RADIUS

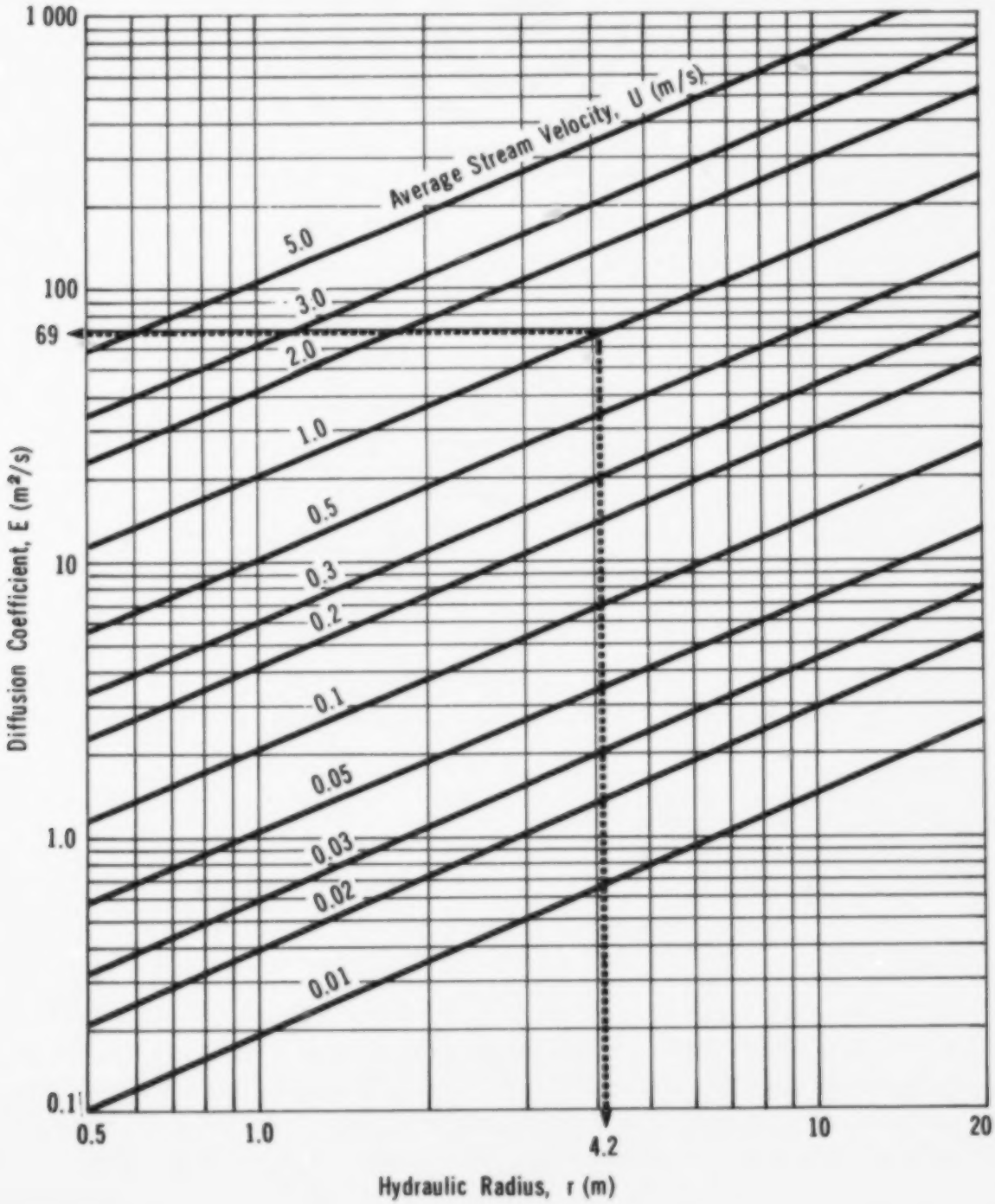


FIGURE 13

SODIUM CHLORATE

ALPHA vs DIFFUSION COEFFICIENT

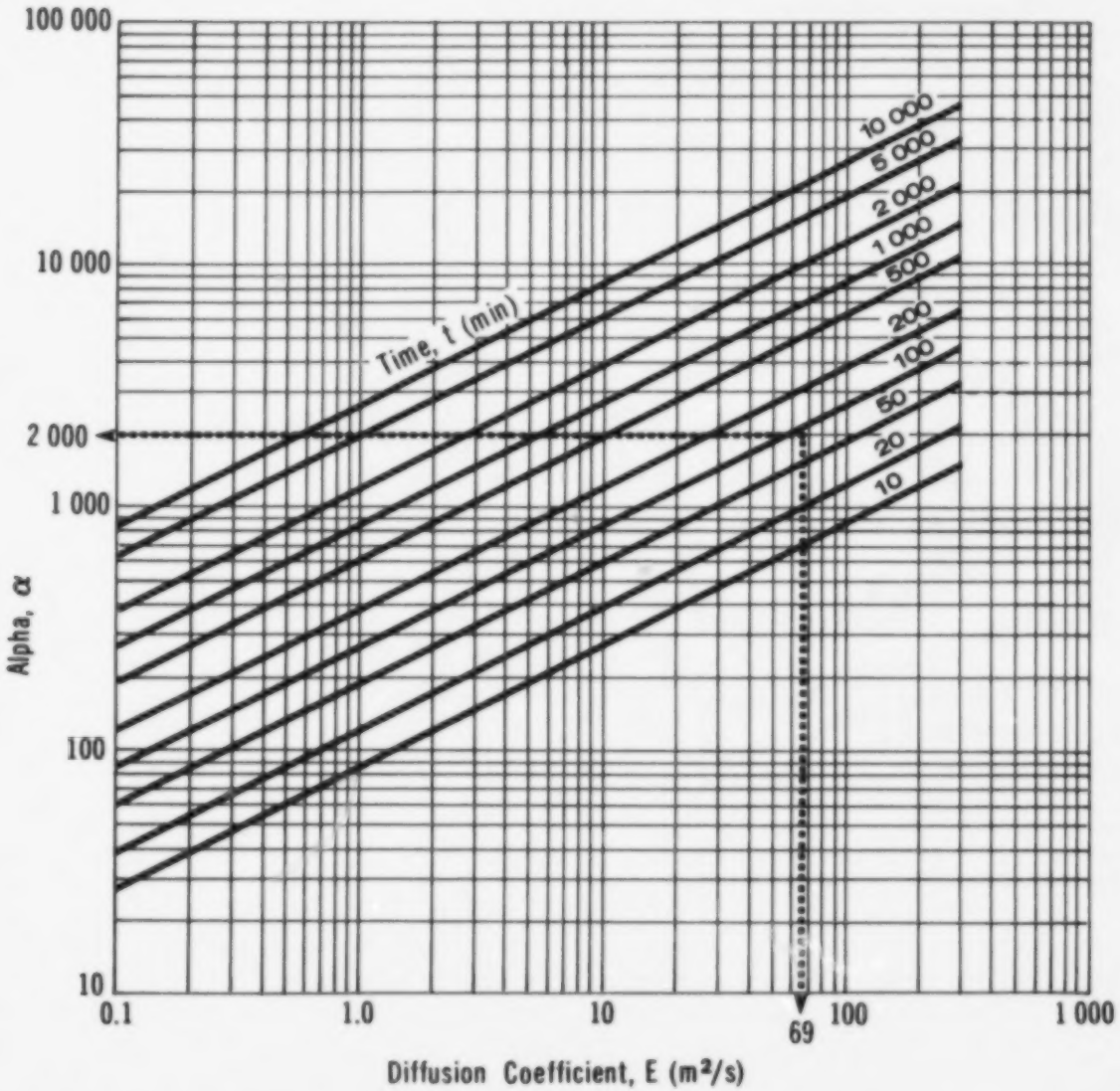


FIGURE 14

SODIUM CHLORATE

ALPHA vs DELTA

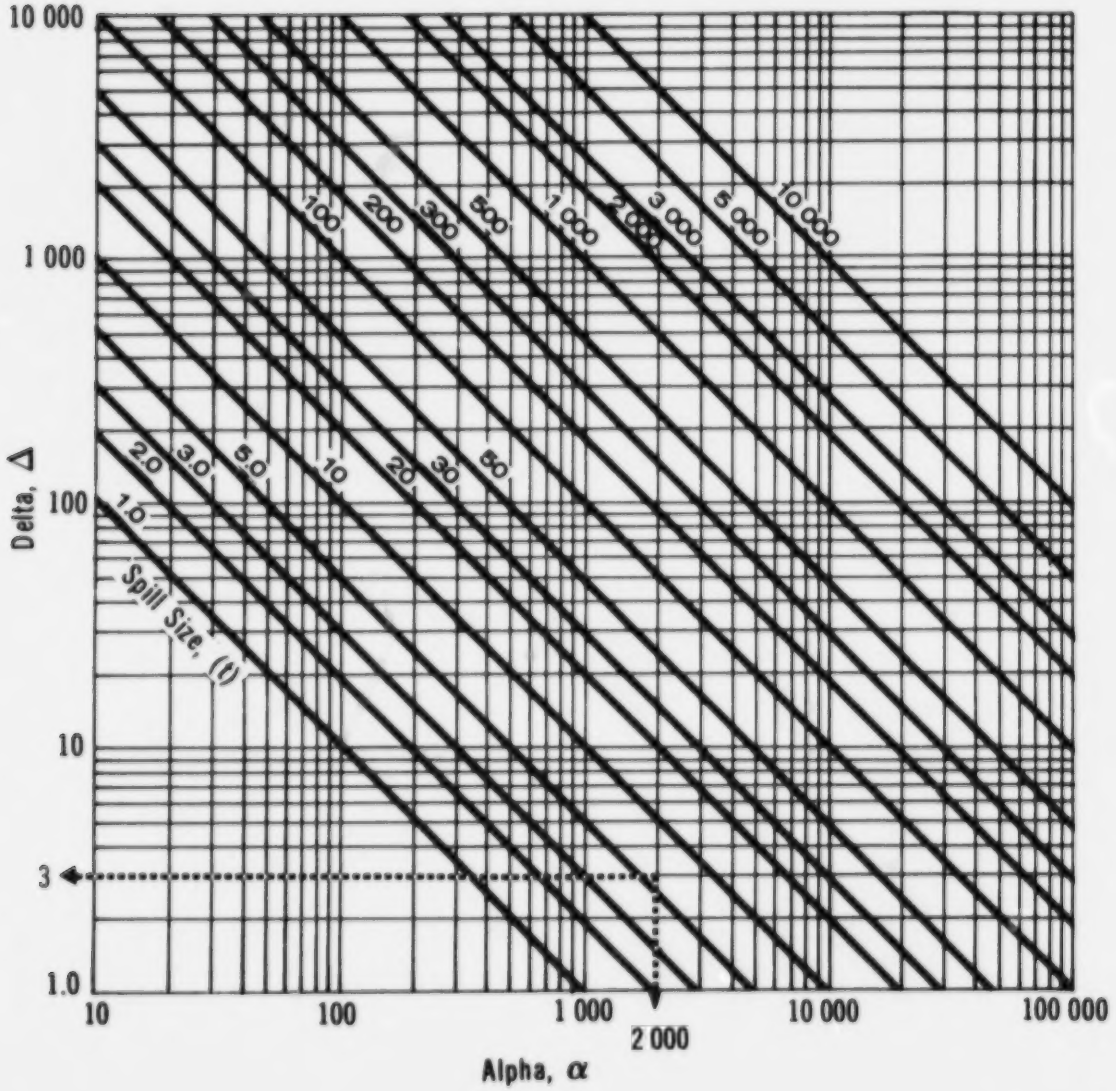


FIGURE 15

SODIUM CHLORATE

MAXIMUM CONCENTRATION vs DELTA

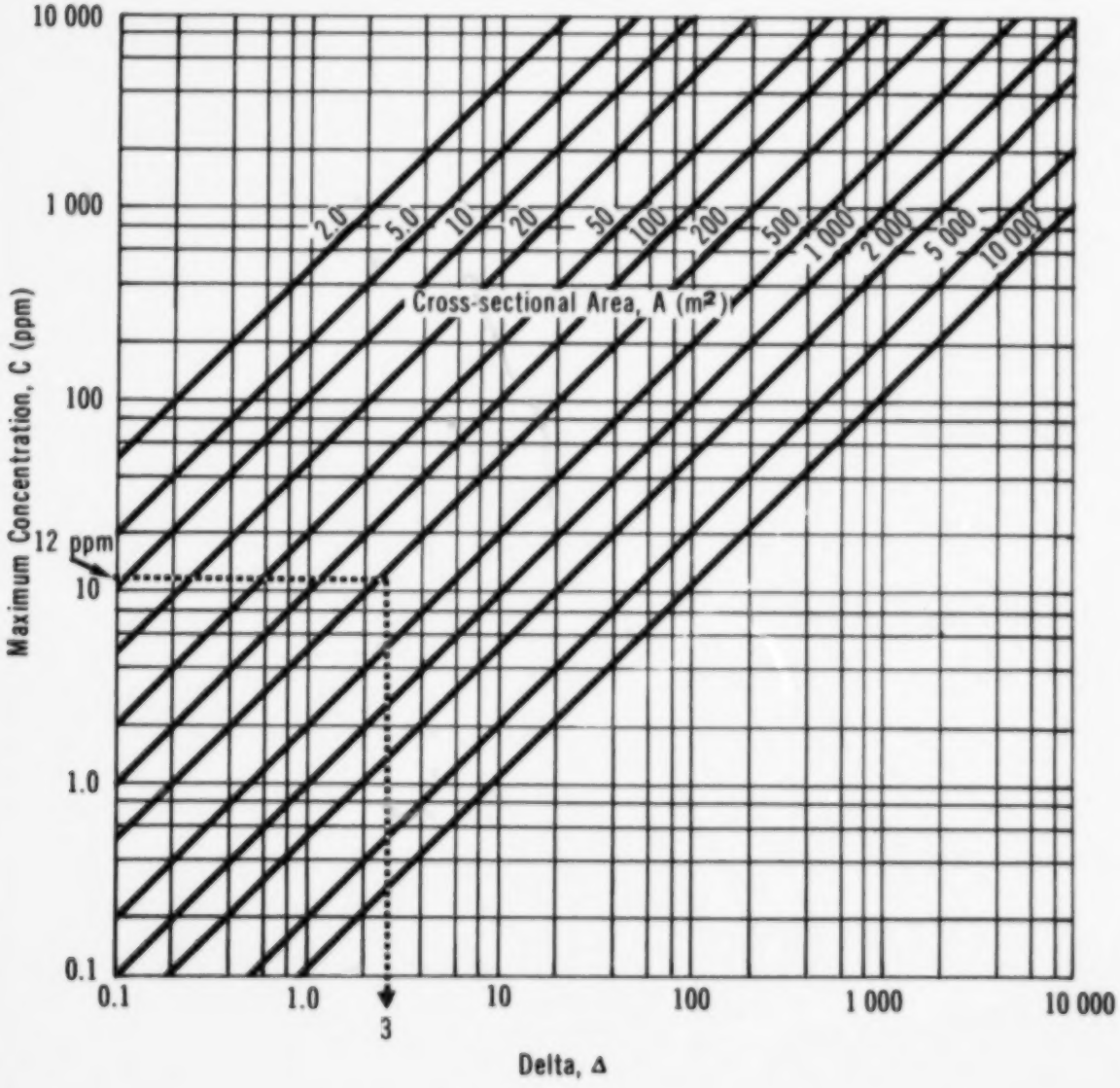


FIGURE 16

SODIUM CHLORIDE

VOLUME vs RADIUS

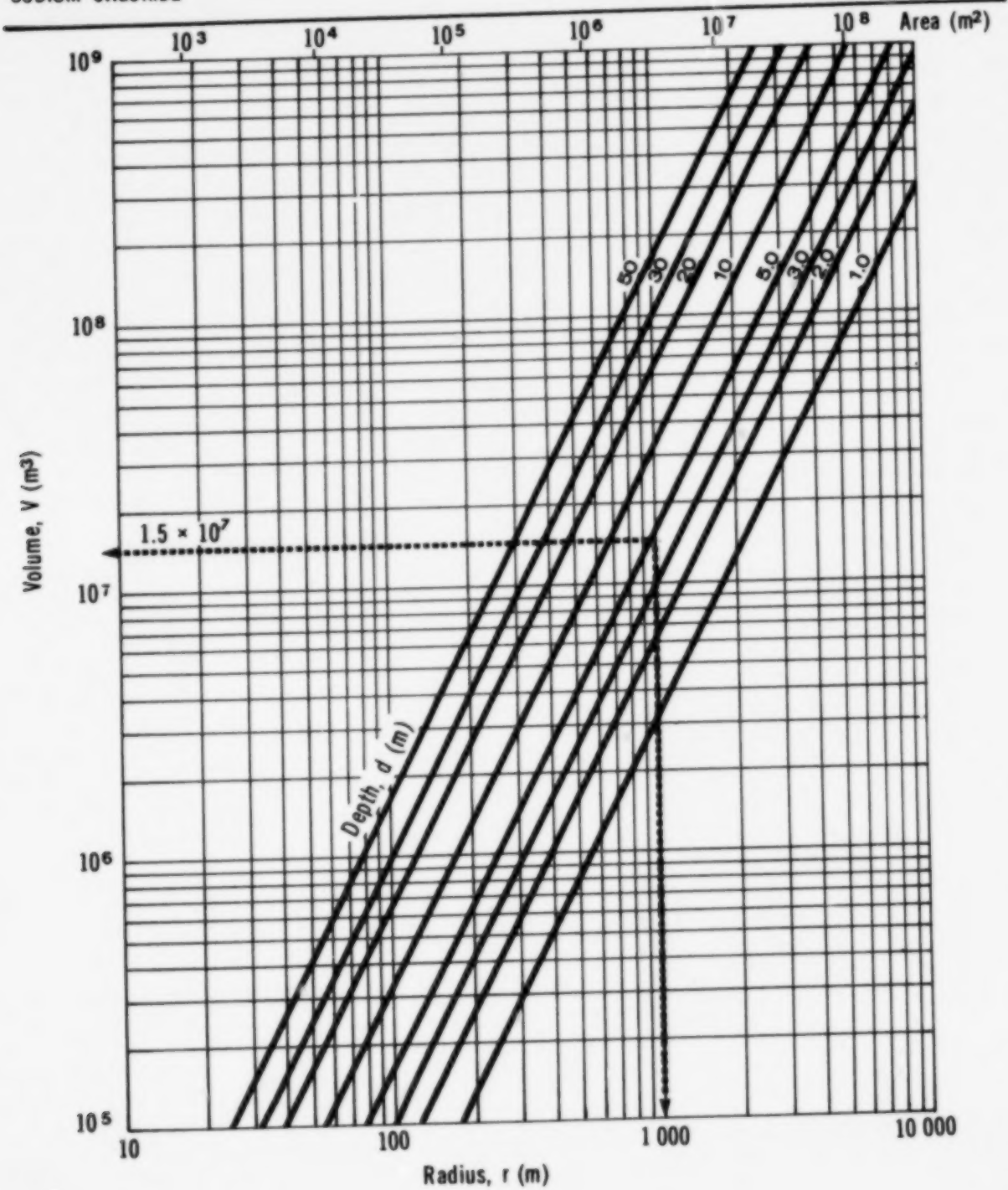
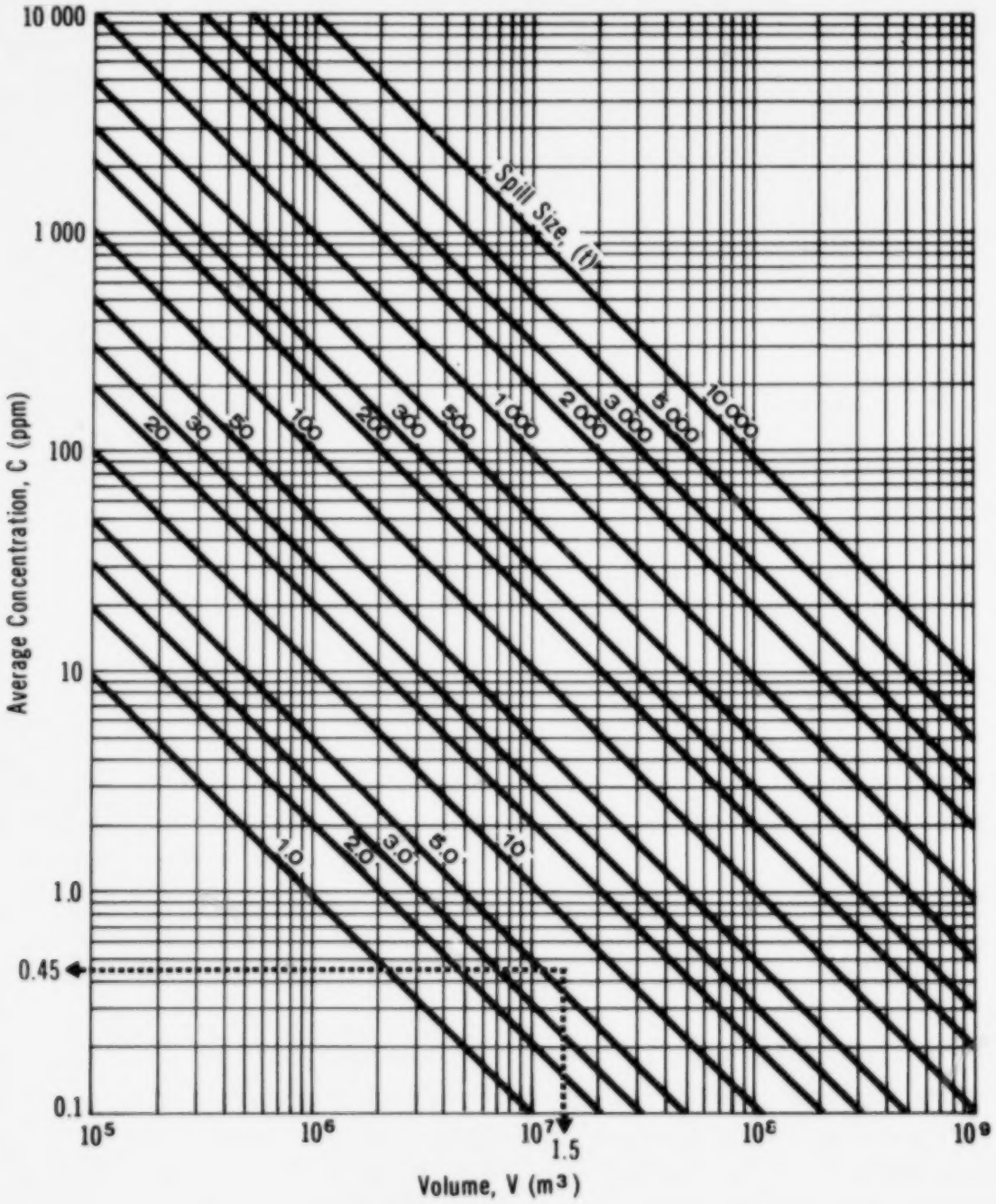


FIGURE 17

SODIUM CHLORATE

AVERAGE CONCENTRATION vs VOLUME



5.4.3 Sample Calculations.

5.4.3.1 Pollutant concentration in non-tidal rivers. A 20 tonne spill of 30 percent sodium chlorate solution has occurred in a river. The stream width is 50 m and the stream depth is 5 m. The average stream velocity is estimated at 1 m/s. What is the maximum concentration expected at a water intake located 5 km downstream?

Solution

Step 1: Define parameters

- W = 50 m
- d = 5 m
- X = 5000 m
- U = 1 m/s
- spill mass = 20 tonnes of 30 percent sodium chlorate solution, contains the equivalent of 6 tonnes of sodium chlorate

Step 2: Calculate the time to reach the point of interest

- Use Figure 10
- With X = 5000 m and U = 1 m/s, t = 83 min

Step 3: Calculate the hydraulic radius (r)

- Use Figure 11
- With W = 50 m and d = 5 m, r = 4.2 m

Step 4: Calculate the longitudinal diffusion coefficient (E)

- Use Figure 12
- With r = 4.2 m and U = 1 m/s, E = 69 m^2/s

Step 5: Calculate alpha (α)

- Use Figure 13
- With E = 69 m^2/s and t = 83 min, α = 2000

Step 6: Calculate delta (Δ)

- Use Figure 14
- With alpha (α) = 2000 and spill mass = 6 tonnes, delta (Δ) = 3

Step 7: Compute the stream cross-sectional area (A)

- A = W x d = 50 x 5 = 250 m^2

Step 8: Calculate the maximum concentration (C) at the point of interest

- Use Figure 15

- With $\Delta = 3$ and $A = 250\ m^2$, C = 12 ppm

5.4.3.2 Average pollutant concentration in lakes or still water bodies. A 20 tonne spill of 30 percent sodium chlorate solution has occurred in a lake. The point of interest is located on the shore approximately 1000 m from the spill. The average depth between the spill site and the point of interest is 5 m. What is the average concentration which could be expected?

Solution

Step 1: Define parameters

- d = 5 m
- r = 1000 m
- spill mass = 6 tonnes (equivalent)

Step 2: Determine the volume of water available for dilution

- Use Figure 16
- With r = 1000 m, d = 5 m, the volume is approximately $1.5 \times 10^7\ m^3$

Step 3: Determine the average concentration

- Use Figure 17
- With $V = 1.5 \times 10^7\ m^3$ and spill mass = 6 tonnes, the average concentration is 0.45 ppm

5.5 Subsurface Behaviour: Penetration into Soil

5.5.1 Mechanisms. The principles of contaminant transport in soil and their application to this work are presented in the Introduction Manual. Special considerations related to the spill of sodium chlorate onto soil and its transport downward through the soil are presented here.

When solid sodium chlorate is spilled, only limited groundwater contamination hazard exists if the soil is dry and if no precipitation falls prior to cleanup. However, if precipitation or other forms of moisture are present, groundwater contamination can be expected.

Since sodium chlorate is very soluble (95.7 g/100 mL at 20°C), concentrated solutions can infiltrate the soil. Some interaction between the contaminant and the soil, probably in the form of ion exchange, will occur. However, much of the salt together with exchanged ions will migrate downward through the soil. If the soil surface is saturated with moisture at the time of the spill, as might be the case after a rainfall, the spilled contaminant dissolved in the precipitation will run off. For this work, the soils

have been assumed to be at field capacity. This situation provides very little interstitial water to dilute the chemical during transport or to impede its downward movement and thus represents "worst case" analysis.

Upon reaching the groundwater table, the contaminant will continue to move, now in the direction of groundwater flow. A contaminated plume will be produced, with diffusion and dispersion serving to reduce the concentration somewhat. This is shown schematically in Figure 18.

5.5.2 Equations Describing Dissolved Sodium Chlorate Movement into Soil. The equations and assumptions used to describe contaminant movement in solution downward through the unsaturated soil zone toward the groundwater table have been described in the Introduction Manual. Transport velocities have been based on Darcy's Law assuming saturated piston flow.

5.5.3 Saturated Hydraulic Conductivity of Dissolved Sodium Chlorate in Soil. The saturated hydraulic conductivity (K_o), in m/s, is given by:

$$K_o = \frac{(\rho g)k}{\mu}$$

where:
- k = intrinsic permeability of the soil (m^2)
- ρ = mass density of the fluid (kg/m^3)
- μ = absolute viscosity of the fluid (Pa·s)
- g = acceleration due to gravity = 9.81 m/s^2

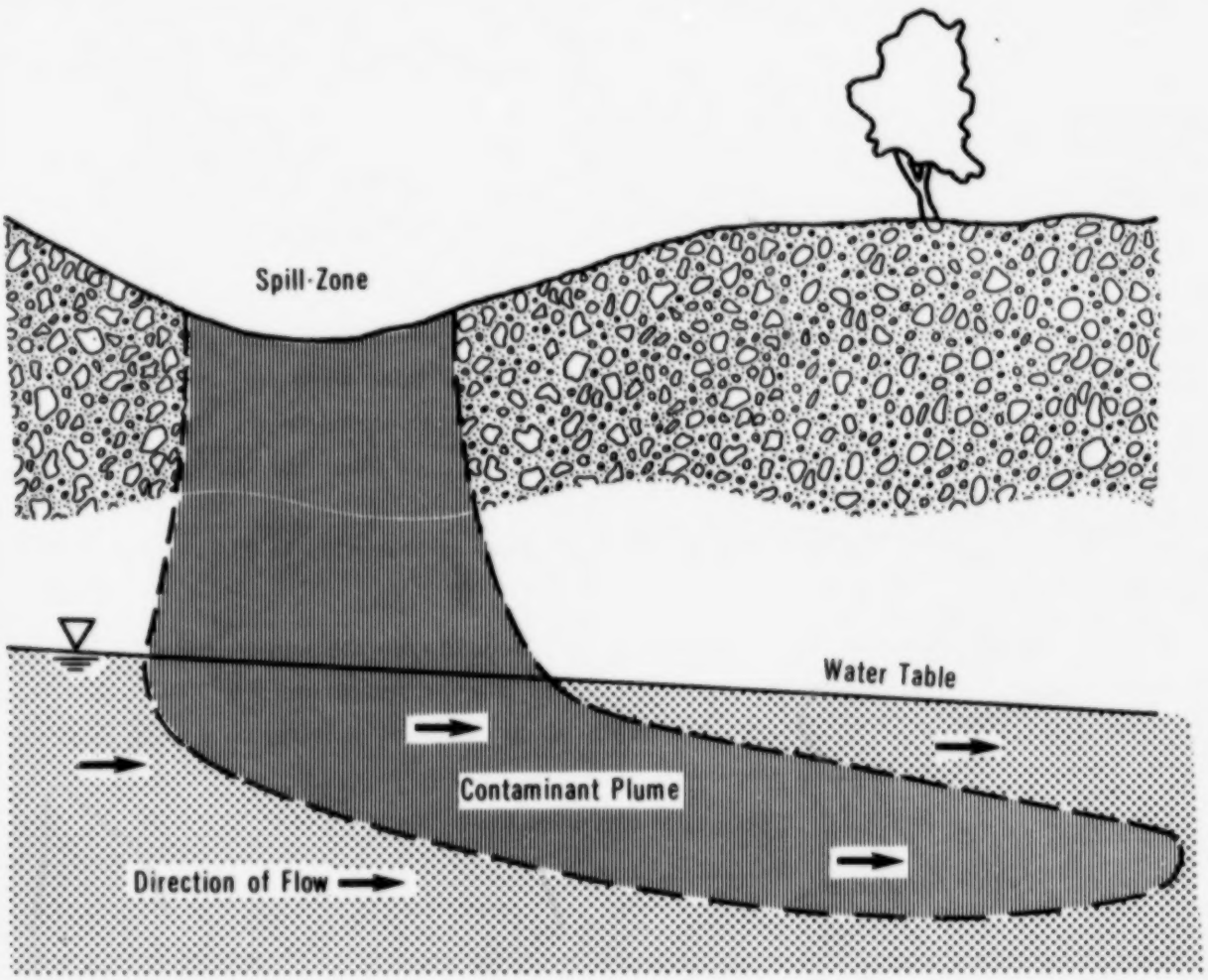
Because of the manner in which the solution is created (that is, precipitation falling on a spilled solid), it is assumed to have fluid properties similar to those of water.

	Dilute Solutions	
Property	4°C	(Water) 20°C
Mass density (ρ), kg/m^3	1000	998
Absolute viscosity (μ), Pa·s	1.57×10^{-3}	1.0×10^{-3}
Saturated hydraulic conductivity (K_o), m/s	$(0.62 \times 10^7)k$	$(0.98 \times 10^7)k$

FIGURE 18

SODIUM CHLORATE

SCHEMATIC SOIL TRANSPORT



Soil: Coarse Sand

- Porosity (n) = 0.35
- Intrinsic Permeability (k) = 10^{-9} m^2
- Field Capacity (θ_{fc}) = 0.075

5.5.4 Soils. The Introduction Manual describes the three soils selected for this work. Their relevant properties are:

Property	Soil Type		
	Coarse Sand	Silty Sand	Clay Till
Porosity (n), m^3/m^3	0.35	0.45	0.55
Intrinsic permeability (k), m^2	10^{-9}	10^{-12}	10^{-15}
Field capacity (θ_{fc}), m^3/m^3	0.075	0.3	0.45

5.5.5 Penetration Nomograms. Nomograms for the penetration of dissolved sodium chlorate into the unsaturated zone above the groundwater table were prepared for each soil. They present penetration time (t_p) plotted against depth of penetration (B). Because of the methods and assumptions used, the penetration depth should be considered as a maximum depth in time t_p.

A flowchart for the use of the nomograms is presented in Figure 19. The nomograms are presented as Figures 20, 21, and 22.

5.5.6 Sample Calculation. A 20 tonne spill of sodium chlorate solution has occurred on silty sand soil. The radius of the spill is 8.6 m and the temperature is 20°C. Rain begins prior to cleanup. Calculate the depth of contaminant penetration 4 days after commencement of the rainfall.

Solution

Step 1: Define parameters

- Mass spilled = 20 000 kg (20 tonnes)
- T = 20°C
- r = 8.6 m
- Soil = silty sand
- Groundwater table depth (d) = 13 m
- Time since spill (t_p) = 4d

Step 2: Calculate the area of the spill

- $A = \pi r^2 = 232\ m^2$

Step 3: Estimate the depth of penetration (B) at time (t_p)

- For silty sand, B = 3.4 m at t_p = 4 d
- Groundwater table has not been reached in this time

FIGURE 19

SODIUM CHLORATE

FLOWCHART FOR NOMOGRAM USE

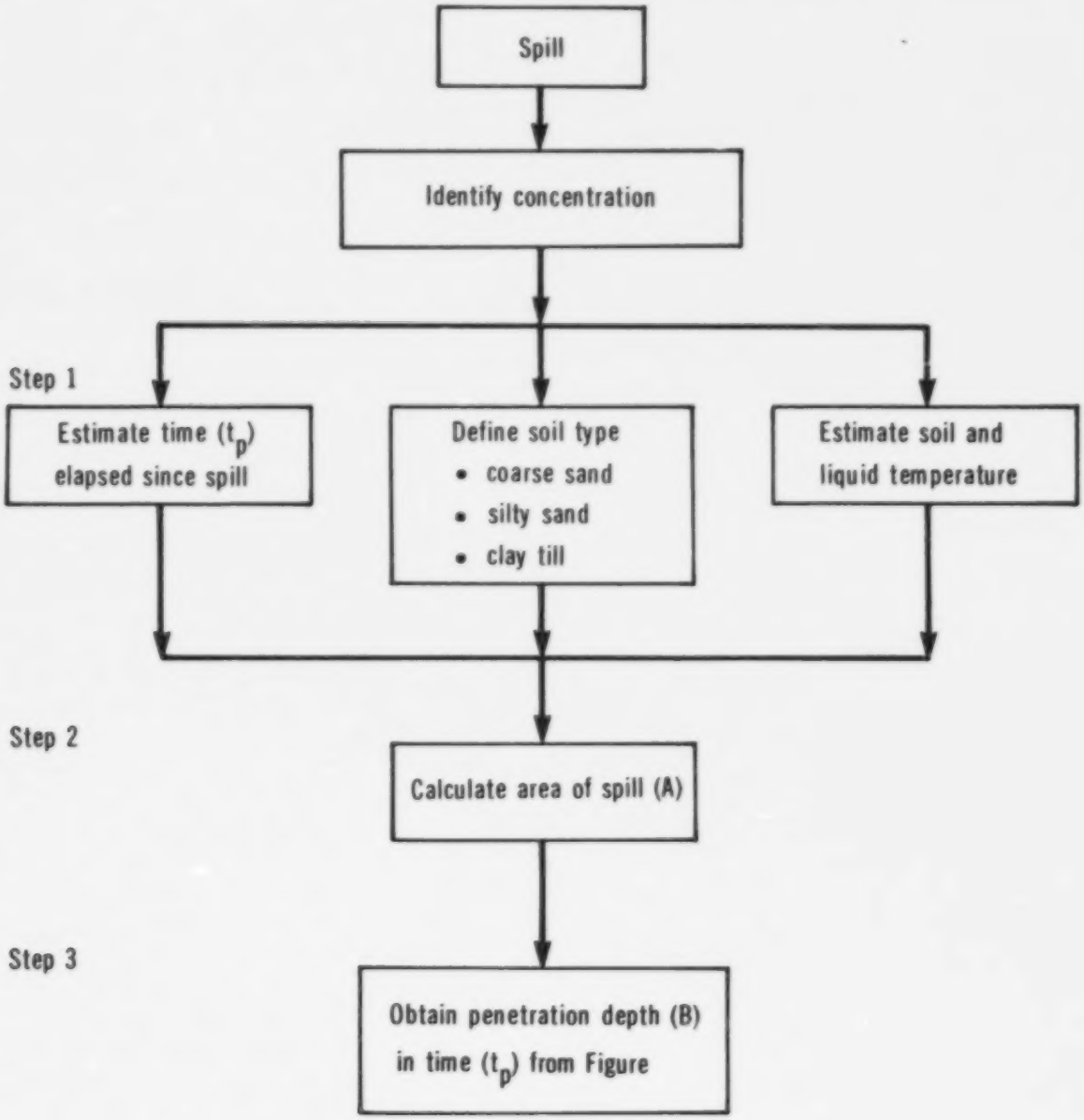


FIGURE 20

SODIUM CHLORATE

PENETRATION IN COARSE SAND

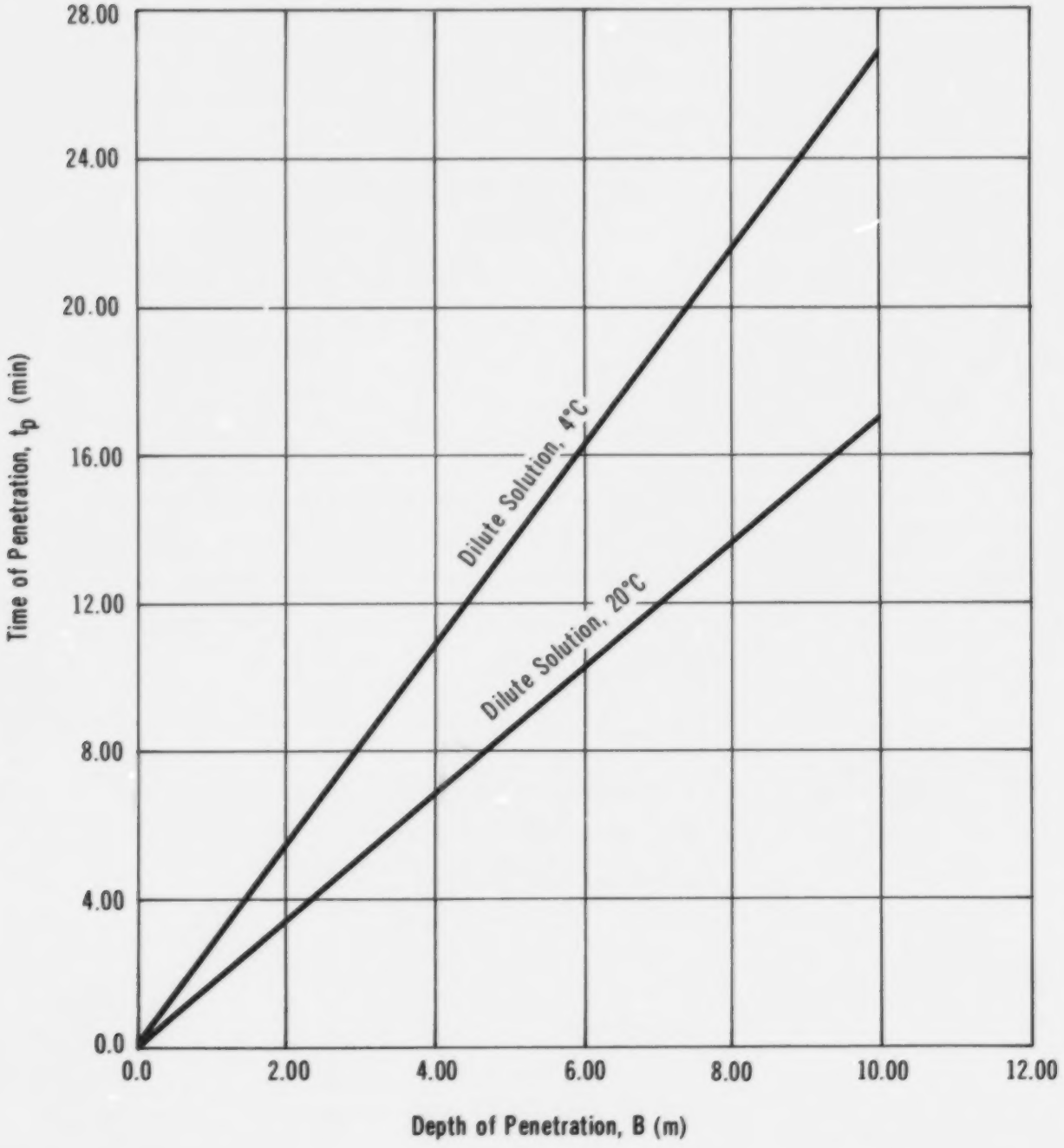


FIGURE 21

SODIUM CHLORATE

PENETRATION IN SILTY SAND

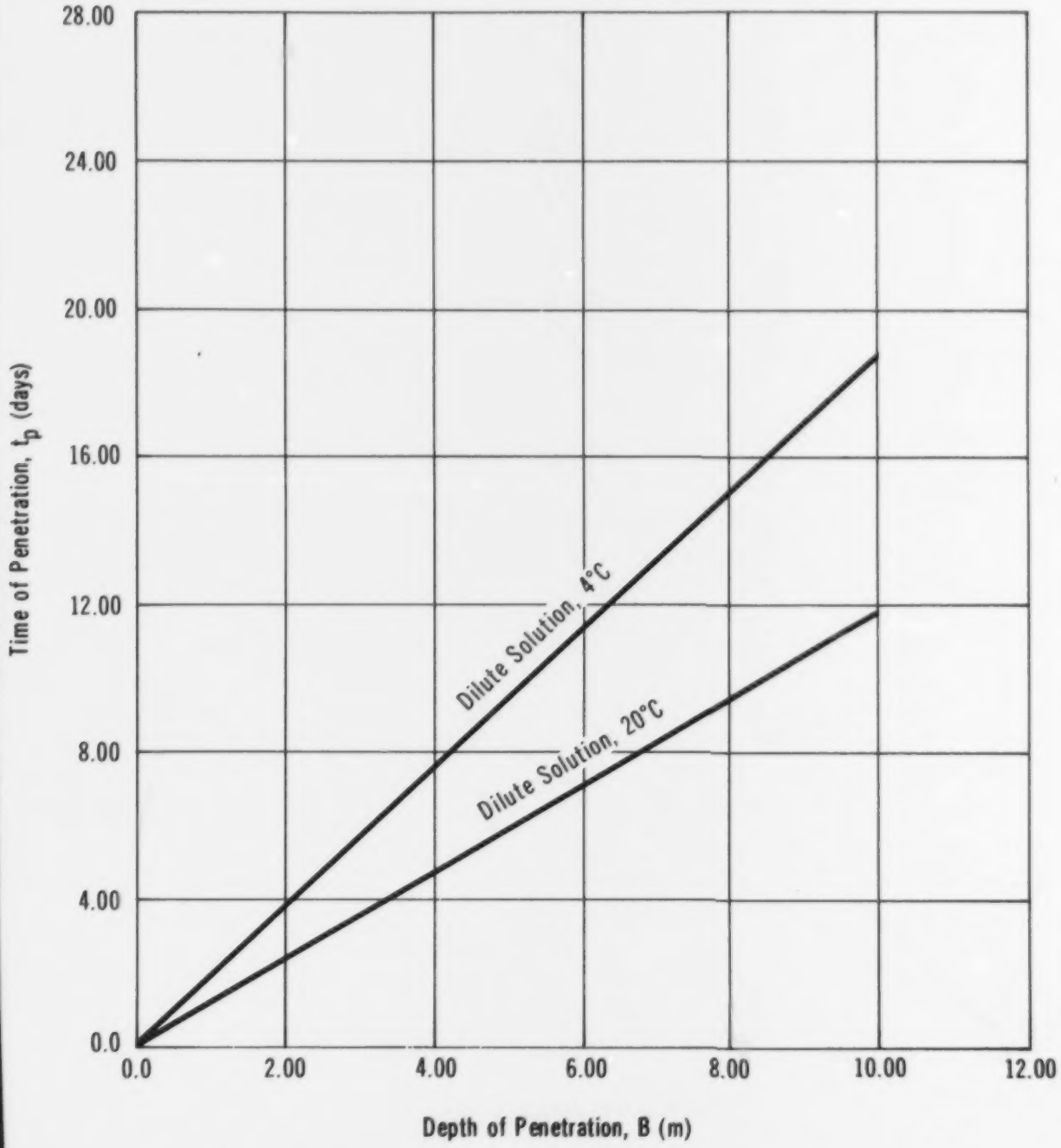
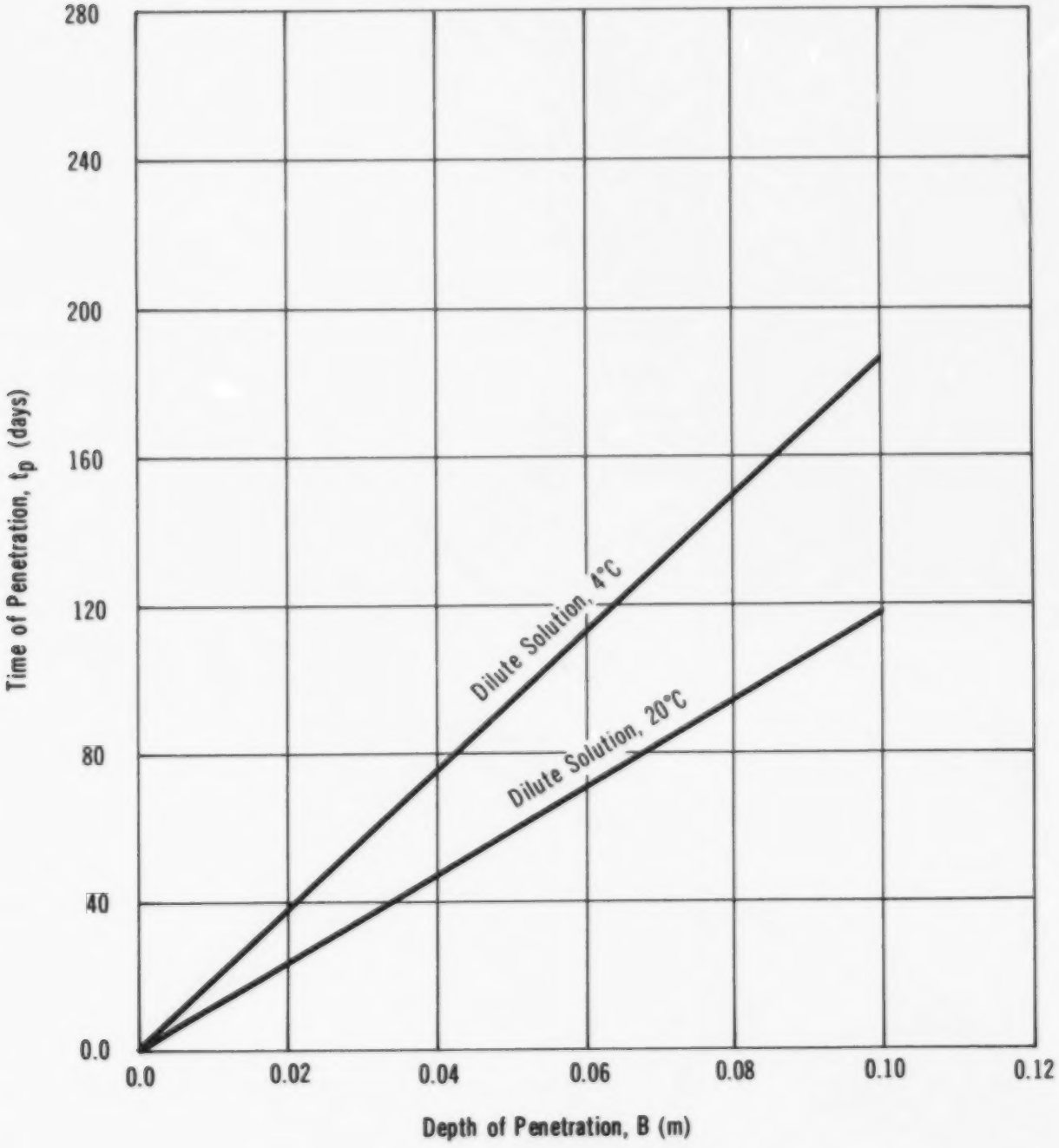


FIGURE 22

SODIUM CHLORATE

PENETRATION IN CLAY TILL



6 ENVIRONMENTAL DATA

6.1 Suggested or Regulated Limits

6.1.1 Water. No regulations specifically relate to sodium chlorate levels in water in Canada or the United States.

6.1.2 Air. Air levels for sodium chlorate are not specifically regulated in Canada or the United States.

6.2 Aquatic Toxicity

6.2.1 U.S. Toxicity Rating. Sodium chlorate has been assigned a TL_m96 of greater than 1000 ppm (RTECS 1979).

6.2.2 Measured Toxicities.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Fish Toxicity Tests					
3157	24	Channel catfish	LC_{50}	-	Pimental 1971
4200	24	Rainbow trout	LC_{50}	-	Pimental 1971
2750	48	Rainbow trout	LC_{50}	static	WQCDB 1971
8600	24	Harlequin fish	LC_{50}	static	Pimental 1971
1750	96	Rainbow trout	LC_{50}	pH 6.3, HD 3.6 15°C	Beech 1983
13 000	tns	Bleak (*Alburnus alburnus*)	threshold toxicity	static, tap water	Shifrer 1974
11 000	tns	Perch	threshold toxicity	static, tap water	WQC 1963
1000	120	Goldfish	safe		WQC 1963
18 000	3.4 to 4.5	Fathead Minnow	LC_{50}	16-28°C	Shifrer 1974
24 000	1.1 to 1.3	Fathead Minnow	LC_{50}	16-23°C	Shifrer 1974
Microorganisms					
3.8	tns	Algae (*Scenedesmus*)	threshold	-	WQC 1963
5.1	tns	Bacteria (*E. coli*)	threshold	-	WQC 1963

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Invertebrates					
4240	tns	*Daphnia magna*	toxic threshold	-	WQC 1963
16 000	-	Planarian worm (*Polycelis nigra*)	toxic threshold	-	WQC 1963

6.3 Mammalian Toxicology

Sodium chlorate has an acute toxicity ranking, based on mammalian ingestion data, of "LD_{50} greater than 5000 mg/kg body weight" (WQCDB-2 1971).

6.4 Avian Toxicity

Chickens exposed to sublethal doses lose weight; fertility is also reduced (OHM-TADS 1981).

6.5 Other Land and Air Toxicity

Sodium chlorate is used as a herbicide; it is toxic to plants, algae and bacteria (OHM-TADS 1981).

6.6 Effect Studies

The effect of sodium chlorate on stream communities at levels up to 57.2 mg/L was studied; no significant effects were noted (Matida 1975).

6.7 Degradation

No degradation data are available. Sodium chlorate has no BOD or COD as it is a strong oxidant and will not persist in a high-organic-content environment.

6.8 Long-term Fate and Effects

An application of sodium chlorate to soil may persist for over a year; however, it will not persist in soils with a high organic content due to its strong oxidizing nature (OHM-TADS 1981).

7 HUMAN HEALTH

Very little information concerning the toxicity of sodium chlorate, administered by any route other than orally, was found in the published literature. No recent reviews of the chemical's toxicity were encountered, and there is no TLV® for sodium chlorate. No information was found concerning potential carcinogenic, mutagenic or teratogenic effects due to sodium chlorate exposure. The toxicological data summarized here have been extracted from reliable standard reference sources. Only acute (short-term) exposure data are given for nonhuman mammalian species, to support interpretation of the human data where appropriate.

7.1 Recommended Exposure Limits

No recommended exposure standards for sodium chlorate were found in the literature.

Exposure Level	Effects	Reference
Other Human Toxicities		
50 to 500 mg/kg	Probable oral lethal dose	TDB (on-line) 1981
214 mg/kg	LD_{LO}	RTECS 1979
185 mg/kg	LD_{50} (child)	RTECS 1979

7.2 Irritation Data

7.2.1 Skin Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
Unspecified	Irritation of the skin	ITII 1981
Unspecified	Not readily absorbed by the skin	TDB (on-line) 1981
SPECIES: Rabbit		
500 mg (24 h)	Mild irritation	RTECS 1979

7.2.2 Eye Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
Unspecified	Conjunctivitis	ITII 1980
SPECIES: Rabbit		
10 mg	Mild irritation	RTECS 1979

7.3 Threshold Perception Properties

7.3.1 Odour. Odour characteristics: Odourless (AAR 1981)

7.3.2 Taste. Taste characteristics: Cooling saline taste (AAR 1981)

7.4 Toxicity Studies

7.4.1 Inhalation.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
Unspecified	Can cause local irritation of skin and mucous membranes	TDB (on-line) 1981

7.4.2 Ingestion.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
2 g	Lethal to 1-year-old child	TDB (on-line) 1981
800 mg/kg	TD_{LO} (woman)	RTECS 1979
185 mg/kg	LD_{50} (child)	RTECS 1980
SPECIES: Cattle		
5000 mg/kg	LD_{50}	TDB (on-line) 1981

Exposure Level (and Duration)	Effects	Reference
SPECIES: Dog		
700 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Cat		
1350 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rabbit		
8000 mg/kg	LD_{LO}	RTECS 1979
SPECIES: RAT		
1200 mg/kg	LD_{50}	RTECS 1979

7.4.3 Mutagenicity, Carcinogenicity and Teratogenicity. No data.

7.5 Symptoms of Exposure

General symptoms of exposure found in most information sources have not been specifically referenced. Only those of a more specific nature have their sources indicated. Symptoms are listed in approximate order of the severity of exposure.

7.5.1 Inhalation (of dust).

1. Irritation of the mucous membranes (TDB (on-line) 1981).
2. Respiratory difficulties (AAR 1981).
3. May cause failure of respiration (AAR 1981).

7.5.2 Ingestion.

1. Gastroenteric pain (CHRIS 1978).
2. Nausea.
3. Vomiting.
4. Diarrhea.
5. Dyspnea (TDB (on-line) 1981).
6. Cyanosis.
7. Hemolysis (TDB (on-line) 1981).
8. Blood urea increase (TDB (on-line) 1981).
9. Acute nephritis.
10. Anuria.

11. Kidney injury (CHRIS 1978).
12. Liver injury (CHRIS 1978).
13. Convulsions (TDB (on-line) 1981).
14. Coma (TDB (on-line) 1981).
15. Death.

7.5.3 Skin Contact.

1. Skin irritation (CHRIS 1978).

7.5.4 Eye Contact.

1. Irritation (CHRIS 1978).
2. Conjunctivitis (ITII 1981).

8 CHEMICAL COMPATIBILITY

8.1 Compatibility of Sodium Chlorate with Other Chemicals and Chemical Groups

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
GENERAL														
Fire	•	•				•							Containers may explode in fire	NFPA 1978
Heat	•	•											Forms explosive and flammable mixtures with combustibles and organics when heated	NFPA 1978
SPECIFIC CHEMICALS														
Aluminum (powder)		•											Can be exploded by heat, friction	NFPA 1978
Ammonium Thiosulphate		•				•								NFPA 1978
Antimony Sulphide		•											Reaction is incandescent and possibly explosive; metals such as cadmium, magnesium or zinc may be necessary for reaction	NFPA 1978

8.1 Compatibility of Sodium Chlorate with Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Arsenic (finely divided)			•										Can be exploded by heat, friction, metals such as cadmium, magnesium or zinc may be necessary for reaction	NFPA 1978
Arsenic Trioxide		•											Spontaneous flammable mixture	NFPA 1978
1, 3-Bis (trichloromethyl) Benzene										•				Bretherick 1979
Carbon (finely divided)			•										Can be exploded by heat, friction; metals such as magnesium, zinc or cadmium may be necessary in mixture	NFPA 1978
Charcoal		•												NFPA 1978
Copper (finely divided)			•										Can be exploded by heat, friction; metals such as magnesium, zinc or cadmium may be necessary in the mixture	NFPA 1978

8.1 Compatibility of Sodium Chlorate with Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Diarsenic Trioxide		•											Ignition on contact	Bretherick 1979
Grease			•											Bretherick 1979
Leather			•										Explodes by spark or friction, when dry	Bretherick 1979
Manganese Dioxide	•		•										Oxygen may also be liberated	NFPA 1978
Nitrobenzene			•										Violently explosive	Bretherick 1979
Organic Matter		•											Hazardous if there is more than 10% sodium chlorate present	Bretherick 1979
Osmium										•			At high temperatures	Bretherick 1979
Phosphorus (red)			•											Bretherick 1979
Phosphorus (white)			•										Violently explosive	NFPA 1978
Potassium Cyanide			•										When heated	NFPA 1978
Sodium Phosphinate			•		•									Bretherick 1979
Sulphur	•		•										Oxygen also liberated; reaction may require presence of metal chlorates	NFPA 1978

8.1 Compatibility of Sodium Chlorate with Other Chemicals and Chemical Groups
(Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Sulphuric Acid		•	•											Bretherick 1979
Wood		•	•											Bretherick 1979
Zinc (powdered)			•										Can be exploded by percussion	NFPA 1978
CHEMICAL GROUPS														
Agricultural Materials	•												e.g. peat, sawdust, pesticides	Bretherick 1979
Ammonium Salts		•	•			•								Bretherick 1979
Diols (Alkenes)			•											Bretherick 1979
Metal Sulphides			•										Explosion can occur by heat or friction; however, cadmium, magnesium or zinc may be required to initiate reaction	NFPA 1978
Organic Acids (Dibasic)			•										When heated, explosive chlorine dioxide is evolved; metal chlorates may be required to produce reactions	NFPA 1978

8.1 Compatibility of Sodium Chlorate with Other Chemicals and Chemical Groups (Cont'd)

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
Organic Matter		•											May ignite spontaneously or by friction or shock	NFPA 1978; Bretherick 1979
Powdered Metals		•	•										Fire and possible explosion with some metals	Bretherick 1979
Reducing Agents			•							•				EPA 600/2-80-076
Strong Acids			•			•								CCPA 1983
Thiocyanates			•										Mixtures explode at a temperature of 390°C or when touched by flame or spark; metal chlorates may be required to produce reaction	NFPA 1978

9 COUNTERMEASURES

9.1 Recommended Handling Procedures

The following procedures have been derived from a literature review. To avoid any deviation from the intended meaning, the wording of the original source has been presented essentially unchanged - in so doing, it is recognized that there may be discrepancies between different sources of information. It is recognized that countermeasures are dependent on the situation, and thus what may appear to be conflicting information may in fact be correct for different situations. The following procedures should not be considered as Environment Canada's recommendations.

9.1.1 Fire Concerns. Sodium chlorate is a noncombustible and powerful oxidizing material (NFPA 1978; Hooker PIM 1977). Intimate mixtures of this material with oxidizable organic substances are potential fire and explosion hazards. Combustible materials, impregnated with chlorate solutions and allowed to dry, can be ignited by means of friction or any other source of ignition. Strong acids and chlorates may react, generating chlorine dioxide gas which is spontaneously explosive in high concentrations (MCA 1952). Containers may explode when involved in a fire (NFPA 1978). Sodium chlorate solutions should never be allowed to dry on clothing or shoes. Ignition can be so quick as to be inextinguishable (CCPA 1983).

9.1.2 Fire Extinguishing Agents. Water is the only effective fire extinguisher. CO_2, dry powder or other smothering-type extinguishers are not effective (Hooker PIM 1977). Use water spray to cool containers involved in a fire to prevent rupture or explosion. Move containers from fire area if this can be done without risk. For massive fires, use unmanned hose holder or monitor nozzles (ERG 1980).

9.1.3 Spill Actions, Cleanup and Treatment.

9.1.3.1 General. Eliminate all sources of ignition. Use rubber clothing. Wash or burn all nonrubber clothing if contaminated.

9.1.3.2 Spills on land. If any spillage of sodium chlorate should occur on wooden floors or surfaces, it must be removed in the dry state by sweeping or vacuum removal. Water must not be used to flush wooden floors since this could cause impregnation of the wood with chlorate (MCA 1952). However, after removing all possible solid material, the surface should be washed with water to ensure that no material is left to work its way into the wood (CCPA 1983).

If spilled in the solid form, shovel material (avoiding dusting) into containers (noncombustible, preferably metal) with covers for recovery or disposal (Olin MSDS 1980). Sodium carbonate, borax or calcium chloride are recommended as fire retardants to be applied to a dry spill situation (Kerr-McGee MSIS 1978). After collecting as much solid as possible, wash down the area with plenty of water.

For spills of solution, contain if possible by forming mechanical and/or chemical barriers to prevent spreading (EPA 670/2-75-042). Recover as much material as possible with pumps or vacuum equipment (Erco MDS). Flush the area after with plenty of water to ensure that no sodium chlorate is left or is very dilute.

9.1.3.3 Spills in water. Contain if possible (EPA 670/2-75-042). Any contaminated water may be treated by adding large volumes of concentrated reducing solutions (hypo, bisulphite or ferrous salt and acidify with 3 M sulphuric acid). When reduction is complete, neutralize with soda ash or dilute hydrochloric acid, depending on pH (OHM-TADS 1981).

9.1.4 Disposal. Waste sodium chlorate must never be discharged directly into sewers or surface waters. Following treatment, either at the spill site or at a waste management facility, the resultant sludge can be disposed of in a secure landfill.

9.1.5 Protective Measures. For entry into a situation where the spilled material and its characteristics are unknown, self-contained breathing apparatus and a totally encapsulated chemical suit should be worn.

If the spilled material is known to be sodium chlorate:

- Safety mono goggles, impervious clothing and self-contained breathing apparatus should be worn (Erco TERP 1979).
- Neoprene and rubber are recommended for gloves, boots, pants and jackets (Erco TERP 1979).
- Protective equipment or shoes made of leather are not recommended (Hooker PIM 1977; Kirk-Othmer 1979).
- Keep contaminated clothing wet until it can be safely laundered (Kerr-McGee MSIS 1978). Easily washable, clean clothing should be worn and removed after use (Hooker PIM 1977). All clothing should be washed or burned after contact with sodium chlorate (CCPA 1983).

- Eye wash stations and deluge-type chemical safety showers should be readily available in areas of use and spill situations (Hooker PIM 1977).

9.1.6 Storage Precautions. Handle and store in a cool, dry, fire-resistant building. Sodium chlorate should be used directly from containers, and containers should be kept tightly covered when not in use. Do not skid or slide drums. Area must be kept clean to prevent contamination if sodium chlorate is spilled.

Avoid contact with organic and combustible materials, acids and reducing substances as these create an extreme fire and explosion hazard. Absolutely no smoking, sparks or open flames should be permitted in any chlorate-handling area (Kerr-McGee MSIS 1978).

10 PREVIOUS SPILL EXPERIENCE

This section contains information on previous spill experience which will be useful to readers in understanding spill response and countermeasures. Only those which meet the criteria are included, and thus, the number of experiences is not an indication of the problems or frequency of spillage. As technology in spill control advances, this section will be updated in future manual revisions to include the most useful information.

10.1 Sodium Chlorate Explosions (TW 1983).

Numerous explosions of sodium chlorate have occurred. In 1983, sodium chlorate stored in a warehouse in Salford near Manchester, England, exploded and caused a severe fire. The chemical was stored in a warehouse along with xylene (an unadvisable practice) and the blast (specific origin unknown) was strong enough to drop dust 10 kilometres away. The explosion was heard 25 km away and forced evacuation of 2000 people. In 1980, sodium chlorate blew up at a warehouse in Barking in East London, England, causing considerable damage and evacuation of 7000 people. In January of 1977, a fire occurred at a warehouse; burning tar fell onto 67 tonnes of sodium chlorate in drums. The explosion was equivalent to 500 kg (1100 lbs.) of TNT exploding and blew debris 6 km. Damage was about $12 000 000 and 12 people were injured. These incidents point to the precautions necessary in storing and dealing with sodium chlorate.

11 ANALYTICAL METHODS

Methods have been documented for the analysis of samples from air, water and soil in a normally equipped chemical laboratory remote from the spill site. Customary sources of standard or recommended analytical methods were consulted, and outlines are presented for each chemical. These sources included publications of the U.S. National Institute for Occupational Safety and Health (NIOSH), the U.S. Environmental Protection Agency (EPA), the American Water Works Association (AWWA), the American Society for Testing and Materials (ASTM), and the American National Standards Institute (ANSI).

If the standard or recommended methods were judged to be reliable and specific enough for the analysis of environmental and materials samples from spill sites and if they do not require highly specialized laboratory equipment, no additional methods were sought.

If especially simple, reliable tests (e.g., commonly used industrial methods) were found, they have been presented as well.

11.1 Quantitative Method for the Detection of Sodium Chlorate in Air

11.1.1 Atomic Absorption Spectrophotometry (NIOSH 1979). A range of 2.1 to 42 $\mu g/m^3$ (0.5 to 9.6 ppb) of sodium chlorate as sodium may be determined by atomic absorption spectrophotometry.

A known volume of air is drawn through a 37 mm diameter cellulose-ester filter of 0.8 μ pore size, housed in a two-piece filter cassette holder. A sample size of 180 L at a flow of 1.5 L/min is recommended.

The filter sample is transferred to a clean 125 mL beaker and 6.0 mL of concentrated nitric acid are added. The beaker is covered with a watch glass and heated to 165°C on a hotplate in a fume hood. The heating is continued until the filter dissolves and a slightly yellow solution is produced. Once the ashing is complete, as indicated by a clear solution, the watch glass is rinsed with 10 percent nitric acid and the rinse placed in the beaker. The solution is then evaporated to dryness on a water bath.

A 5 mL volume of 10 percent nitric acid is added to the beaker and the solution heated for 5 minutes at 100°C. The solution is quantitatively transferred to a 10 mL volumetric flask. A 0.2 mL volume of lanthanum (50 mg/mL) is added. The volume is then taken to mark with 10 percent nitric acid.

A 2 mL volume of the sample is aspirated into the flame of a suitable atomic absorption spectrophotometer equipped with air-acetylene and nitrous oxide-acetylene

burner heads, a deuterium hollow cathode lamp, two-stage regulators for air, acetylene and nitrous oxide, as well as heating tape and rheostat for nitrous oxide regulation.

The absorbance is determined at 589.6 nm and the concentration determined using a calibration curve.

11.2 Qualitative Method for the Detection of Sodium Chlorate in Air

Sodium chlorate as sodium in air may be determined by a flame test. The sample is collected and digested as in Section 11.1.1. A clean platinum wire is dipped into a portion of sample and placed in the hottest part of a bunsen burner flame. A bright yellow, intense flame indicates sodium (Welcher 1955).

11.3 Quantitative Method for the Detection of Sodium Chlorate in Water

11.3.1 Flame Photometry (ASTM 1979). Concentrations greater than 1 mg/L (ppm) of sodium chlorate as sodium may be determined by flame photometry.

A minimum of 2 L of representative sample is collected in an appropriate container. A suitable volume of sample is atomized into the flame of a suitable flame photometer and the emission intensity determined at 589 nm. The sample concentration is determined using a calibration curve.

11.4 Qualitative Method for the Detection of Sodium Chlorate in Water

Large concentrations of sodium chlorate as sodium in water may be determined by a flame test. The sample is collected as in Section 11.3.1. A clean platinum wire is dipped into a portion of sample and placed in the hottest part of a bunsen burner flame. A bright yellow, intense flame indicates sodium (Welcher 1955).

11.5 Quantitative Method for the Detection of Sodium Chlorate in Soil

11.5.1 Flame Photometry (Hesse 1972). A variable range of concentrations of sodium chlorate as sodium in soil may be determined depending on the aliquot of extract atomized into a suitable flame photometer.

A 5 g sample of 2 mm soil (screened on 2 mm sieve), accurately weighed, is placed in a 50 mL narrow neck centrifuge tube. A 30 mL volume of 0.5 M magnesium acetate solution is added, the tube stoppered, and centrifuged for 5 minutes at 400 rev/s. The supernatant is decanted into a 100 mL volumetric flask. The extraction is repeated twice more and the extracts combined in the volumetric flask. The combined extracts are diluted to volume with 0.5 M magnesium acetate. A suitable aliquot of sample is

atomized into the flame of a suitable flame photometer and the emission intensity determined at 589 nm. The sample concentration is determined using a calibration curve.

11.6 Qualitative Method for the Detection of Sodium Chlorate in Soil

Large concentrations of sodium chlorate as sodium in soil may be determined by a flame test. The sample is collected and extracted as in Section 11.5.1. A clean platinum wire is dipped into a portion of sample and placed in the hottest part of a bunsen burner flame. A bright yellow, intense flame indicates sodium (Welcher 1955).

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EnviroTIPS

Common Abbreviations

BOD	biological oxygen demand
b.p.	boiling point
CC	closed cup
cm	centimetre
CMD	count median diameter
COD	chemical oxygen demand
conc	concentration
c.t.	critical temperature
eV	electron volt
g	gram
ha	hectare
Hg	mercury
IDLH	immediately dangerous to life and health
Imp. gal.	imperial gallon
in.	inch
J	joule
kg	kilogram
kJ	kilojoule
km	kilometre
kPa	kilopascal
kt	kilotonne
L	litre
lb.	pound
LC_{50}	lethal concentration fifty
LC_{LO}	lethal concentration low
LD_{50}	lethal dose fifty
LD_{LO}	lethal dose low
LEL	lower explosive limit
LFL	lower flammability limit
m	metre
m	meta
M	molar
MAC	maximum acceptable concentration
max	maximum
mg	milligram
MIC	maximum immission concentration
min	minute or minimum
mm	millimetre
µg	microgram
µm	micrometre
°Be	degrees Baumé (density)
MMAD	mass median aerodynamic diameter
MMD	mass median diameter
m.p.	melting point
MW	molecular weight
N	newton
NAS	National Academy of Sciences
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
nm	nanometre
o	ortho
OC	open cup
p	para
P_c	critical pressure
PEL	permissible exposure level
pH	measure of acidity/alkalinity
ppb	parts per billion
ppm	parts per million
P_s	standard pressure
psi	pounds per square inch
s	second
STEL	short-term exposure limit
STIL	short-term inhalation limit
T_c	critical temperature
TC_{LO}	toxic concentration low
Td	decomposition temperature
TD_{LO}	toxic dose low
TL_m	median tolerance limit
TLV	Threshold Limit Value
Ts	standard temperature
TWA	time weighted average
UEL	upper explosive limit
UFL	upper flammability limit
VMD	volume mean diameter
v/v	volume per volume
w/w	weight per weight